Chapter 2

Review of Related Literature

2.1 Nanofluid

Nanofluid, a suspension of ultrafine particles (1-100nm) in a base fluid, introduced by Choi & Eastman, 1995, tends to stabilize and upgrade the thermal properties of the fluid that boosted its acceptance. Since then, scientists have been working hard to further enhance heat transfer capabilities. Nanomaterials play a crucial role in medical and engineering applications due to their ability to enhance heat and mass transfer capabilities. According to Song et al., 2021 and Oke et al., 2021, the inherent nature of nanoparticles is bound to affect the temperature distribution. Mackolil & Mahanthesh, 2019 noted that the augmenting nanoparticle volume fraction tends to increase the nanoliquid temperature in an unsteady nanoliquid flow past an inclined plate. Sheikholeslami & Ganji, 2013 studied the heat transfer capabilities of water-based Cu nanomaterial between parallel plates using HPM (homotopy perturbation method). The authors found that the heat transport improved with higher nanoparticle volume fraction. The copper-based nanomaterial flow over an elongated surface was studied by Ahmad, Ijaz Khan, Hayat, & Alsaedi, 2020. The comparative analysis revealed that the nanomaterial temperature and velocity are higher for water-based copper nanomaterial. Further, the authors found that nanoparticle volume fraction has a constructive effect on the heat transfer rate. Hazarika, Ahmed, & Chamkha, 2021 used fourth order RK-shooting technique to numerically investigate the MHD flow of a chemically reacting water based nanofluid over a permeable stretching sheet involving chemical reaction, thermophoresis, heat source and viscous dissipation. Kameswaran, Narayana, Sibanda, & Murthy, 2012 utilized water-based copper and water-based silver nanofluids to investigate the impact of pertinent parameters on the hydromagnetic nanofluid flow over a lengthening sheet considering chemical reaction and viscous dissipation effects. It is observed that water-based copper nanofluid exhibits better mass and heat transfer rates.

Ferro-nanofluid (fluid suspension of nanosized magnetite particles) spot applications in biosensors, hyperthermia, microchip pump, targeted drug delivery, and micro-actuators [see Rout et al., 2021]. On administering magnetic field, an increase (of nearly 300%) in the heat transport coefficient of ferro-nanofluid was reported by Azizian et al., 2014. An amplification in the thermal conductivity of Jeffery nanofluid on dispensing magnetite nanoparticles was observed by Sandeep, Chamkha, & Animasaun, 2017. The negative effect of the magnetic parameter on the heat transfer rate of the ferro-nanofluid flow on a rotating disk was pointed out by Z. Abbas, Naveed, Tabassum, & Ahmad, 2021.

Particles of silver between 1nm and 100nm, called silver nanoparticles, have been proved to be beneficial in the medical field with their antibacterial properties and also due to their applicability in the treatment of many diseases; namely cancer [see Mathur, Jha, Ramteke, & Jain, 2018; Foulkes, Ali Asgari, Curtis, & Hoskins, 2019; Hepokur et al., 2019]. Abbasi, Hayat, & Ahmad, 2015 examined the peristaltic transport of silver-water nanofluid in the presence of constant applied magnetic field considering Ohmic heating, velocity slip, thermal slip, and Hall effects. The authors observed that the addition of 5% silver nanoparticles reduced the velocity and temperature of the base fluid by 10% and 16%, respectively. The dominating nature of silver nanoliquid over copper nanoliquid on the heat transfer rate was observed by Hayat, Qayyum, Imtiaz, & Alsaedi, 2016 and Sravanthi, 2019. In addition, Hayat, Khan, Qayyum, & Alsaedi, 2018 noted that the Bejan number is more for Ag-water nanofluid. The increment of the average Nusselt number by increasing the volume fraction of nanoparticles for typical nanofluid is more sensible than hybrid nanofluid in an enclosure with rotating heat sources [see Jamiatia, 2019]. The study on the hydrothermal and irreversibility behaviour of a biologically synthesized silver-water nanoliquid in a wavy microchannel heat sink, conducted by Al-Rashed et al., 2019, revealed that the nanoliquid has a better cooling performance in comparison with pure water.

CNT (carbon nanotube) is a graphene sheet rolled up into a tube having a nanoscale diameter. CNTs are categorised into SWCNT (single-wall carbon nanotubes) and MWCNT (multi-wall carbon nanotubes) based on the number of used graphene sheets. CNT finds its use in structural reinforcement, automotive parts, device modelling, energy storage, electromagnetic shields, etc. CNTs are also proved to be useful in the medical field. CNTs are administered in drug delivery, cancer diagnosis & treatment, thermal ablation, delivery of genetic material, etc. Practically, SWCNTs are preferred over MWCNTs due to the amelioration it provides in the medical field and also due to their lower toxicity level. The significance of nonlinear thermal radiation and quartic chemical reactions on CNT-water nanomaterial flow over a lengthening surface has been explored by R. Kumar, Kumar, Sheikholeslami, & Chamkha, 2019. A higher Nusselt number is noted for SWCNTs than MWCNTs. In addition, the heat transfer growth subject to different CNTs and induced magnetic field (IMF) has been examined by M. Raza et al., 2020. Nadeem, Hayat, & Khan, 2019 conducted a numerical study to reveal that water-based SWCNT-MWCNT hybrid nanoliquid has a better heat transfer rate when balanced against SWCNT-water nanoliquid. Sreedevi & Reddy, 2019 performed a comparative study on the effect of water-based SWCNTs and MWCNTs Maxwell nanoliquid flow between two stretchable rotating disks. M. I. Khan, Hayat, Shah, & Haq, 2019 elucidated the impact of CNTs on stagnation flow over a stretched surface involving quartic chemical reaction and induced magnetic field. Z. Iqbal, Azhar, & Maraj, 2017 conducted a numerical investigation to exploit the response of induced magnetic field on transfer quantities using MWCNT and SWCNT and noted a constructive effect for nanoparticle volume fraction on the induced magnetic field.

2.2 Hybrid Nanofluid

Fluids constituting two or more nanoparticles are termed hybrid nanofluids. Mabood, Yusuf, & Khan, 2021 investigated the significance of melting heat transfer, magnetic field, and nonlinear radiation on hybrid nanoliquid flow over a stretched surface and observed that augmenting nanoparticle volume fraction of copper tends to increase the heat transfer rate. The consequence of the Newtonian heating process and nonlinear thermal radiation effect on water-based $Cu - Ti_2O_3$ hybrid nanofluid flow over an elongating porous surface considering Darcy-Forchheimer's model was analyszed by Yusuf, Mabood, Khan, & Gbadeyan, 2020. The authors noticed that the rate of entropy generation upsurged for ordinary nanofluid when compared with the hybrid nanofluid. Waini, Ishak, & Pop, 2019a explored the two-dimensional steady flow of water-based $Al_2O_3 - Cu$ hybrid nanoliquid over a nonuniformly shrinking/stretching permeable surface. R. Ali, Asjad, & Akgül, 2021 remarked that the water-based hybrid nanoliquid improved the nanofluid temperature and velocity profiles when compared with engine oil-based nanofluid. Junoh, Ali, Arifin, Bachok, & Pop, 2019 studied the hydromagnetic (MHD) stagnation point hybrid nanofluid flow over a stretching/ shrinking sheet and observed an increased heat transfer rate in the hybrid nanofluid when compared with the normal nanofluid. Subhani & Nadeem, 2019 performed a comparison study on the regular and hybrid nanofluid flow induced by an exponentially stretching surface along with micropolar fluid theory. The authors perceived a higher temperature and heat transfer rate in the case of hybrid nanofluid. Agrawal, Dadheech, Jat, Baleanu, & Purohit, 2021 adopted the Runga-Kutta fourth-order method to investigate the MHD radiative flow through a permeable stretching surface immersed in a porous medium. The authors also conducted a parallel analysis on three types of hybrid nanofluids. Ramesh, Shehzad, & Tlili, 2020 explored the Darcy-Forchheimer hybrid nanomaterial flow in a stretchable convergent and divergent channel. For higher solid volume fractions, an enhancement in the velocity of the convergent channel and a decline in the velocity of the divergent channel were noted. Ramesh, Shehzad, & Izadi, 2020 inquired about the thermal transportation of hybrid and regular nanofluids flow due to a moving thin needle. The authors observed that the temperature profile improved in the hybrid nanofluid case. A reduction in the heat transfer rate (upper branch) on the shrinking sheet was observed by Waini, Ishak, & Pop, 2019b with mounting volume fraction of copper nanoparticles. Aly & Pop, 2020 performed a comparative study between hybrid nanofluid and regular nanofluid on the MHD stagnation-point flow over a stretching/shrinking sheet. The numerical exploration performed by Jamaludin, Naganthran, Nazar, & Pop, 2020 reveals that the hybrid nanofluid exhibited the highest temperature and the lowest heat transfer rate. Lund, Omar, Raza, & Khan, 2021 illustrated the dual solutions for dissipative MHD hybrid nanofluid flow past a stretching/shrinking surface and noticed an escalation in the temperature with augmenting values of Eckert number.

2.3 Blood-based Nanofluid

Blood is a connective tissue in fluid form [see Sembulingam & Sembulingam, 2012]. Blood flow utilizing nanoparticles are important in the medical industry for cancer treatment and drug delivery. The significance of partial slip and buoyancy on the blood-gold Carreau nanofluid flow over an upper horizontal surface of a paraboloid of revolution was investigated by O. K. Koriko et al., 2018. The authors observed that the maximum values for surface drag and the heat transfer rate was showcased by smaller values of Deborah number. The augmentation in the volume fraction of carbon nanotubes increased the blood temperature (see Khalid, Khan, Khan, Shafie, & Tlili, 2018). Dinarvand, Rostami, Dinarvand, & Pop, 2019 pointed out that the use of CuO and Cu hybrid nanoparticles reduced the haemodynamic effect of the capillary relative to the pure blood case. U. Khan, Bilal, Zaib, Makinde, & Wakif, 2022 numerically simulated the nonlinear radiative flow of Casson gold-nanoliquid through a stretched rotating rigid disk subject to Lorentz force utilizing the three-stage Lobatto method. Ashraf, Qasim, Wakif, Afridi, & Animasaun, 2022 utilized the generalized differential quadrature method to explore the peristaltic flow of blood-based Casson nanomaterial containing platelet-shaped magnetite nanoparticles. Eid, Al-Hossainy, & Zoromba, 2019 conducted a numerical study on the MHD blood-based SWCNT nanofluid flow through a circular cylinder considering linear heat source/sink, nonlinear thermal radiation, and nanoparticle shape effect. The authors observed that both velocity and temperature profile increase for augmenting heat source/sink, thermal radiation and SWCNT volume fraction with respect to lamina and cylinder shapes. Further, the significance of partial slip due to lateral velocity and viscous dissipation for blood-gold Carreau nanomaterial and dusty fluid was elucidated by O. K. Koriko, Adegbie, Shah, Animasaun, & Olotu, 2021. A significant difference in the effect of partial slip on the dynamics of dusty fluid and blood-gold nanomaterial was observed.

2.4 Nanoparticle Shape and Radius

Different nanoparticle shape and radius exhibit different thermal properties that are beneficial in industrial and biomedical fields. The nanoparticles can be categorized into spherical and non-spherical nanoparticles based on their physical shape. Different shaped nanoparticle exhibits different properties and different heat transfer capabilities (see Truong, Whittaker, Mak, & Davis, 2015). Timofeeva, Routbort, & Singh, 2009 analyzed the thermophysical properties of alumina nanofluid with different nanoparticle shapes; namely platelet, blade, brick, and cylinder; both practically and theoretically. Ellahi, Hassan, & Zeeshan, 2017 pointed out that the lowest velocity and highest temperature of the nanoliquid were caused by the sphere and disc-shaped particles, respectively for the mixed convective nanoliquid flow past a vertical lengthening permeable sheet. In addition, Benkhedda, Boufendi, Tayebi, & Chamkha, 2020 reported that the maximum friction factor is exhibited by the platelet-shaped silver-titanium dioxide nanoparticles. The reduction in the temperature profile of $Cu - CuO$/blood with the increasing shape factor values was revealed by Tripathi, Prakash, Tiwari, & Ellahi, 2020. A comparative analysis of $Ti - H_2O$ and $Ag - H_2O$ nanofluids on the effect of nanoparticle shape in a microchannel, conducted by Sindhu & Gireesha, 2021, showcased that the silver nanofluid exhibited higher entropy than the titanium nanofluid. The authors also observed that the entropy generation is high in the case of disc-shaped nanoparticles, followed by needle and sphere-shaped nanoparticles. Elnaqeeb, Animasaun, & Shah, 2021 investigated the dynamics of water conveying nanoparticles with various densities and shapes through a rectangular closed domain and observed that the heat transfer is maximal in the case of ternary-hybrid nanofluid made up of copper oxide, copper, and silver nanoparticles. The changes in the radius of the nanoparticle is proportional to the velocity profile and inversely proportional to the thermal field (see N. A. Shah et al., 2021). Sun et al., 2022 noted that the augmentations in nanoparticle radius tends to magnify the skin friction coefficient whereas Verma, Rajput, Bhattacharyya, & Chamkha, 2022 and Akbar et al., 2022 noticed a decrease in the drag coefficient.

2.5 Carreau Nanofluid

For a generalized Newtonian fluid, the value of shear rate depends only on its current time point, i.e., there is no memory or history of deformation. Carreau fluid is one such fluid whose viscosity μ depends on the shear rate, which is based on the equation:

$$\mu\left(\dot{\gamma}\right) = \mu_\infty + \left(\mu_0 - \mu_\infty\right)\left(1 + \left(\lambda\dot{\gamma}\right)^2\right)^{\frac{n-1}{2}} \tag{2.5.1}$$

where λ is the relaxation time, $\dot{\gamma}$ is the generalised shear rate, n is the power-law index, μ_0 represents the zero shear viscosity, and μ_∞ is the infinite shear viscosity. Human blood is an example of Carreau fluid with shear thinning nature.

Numerous studies concerning Carreau nanoliquid with variable geometry, boundary conditions and effects have been carried out. Madhu et al., 2020 used FEM to discuss the impact of second law utilization on Carreau fluid flow caused due to a tilted microchannel. The authors observed a decline in temperature due to the augmentation in the Weissenberg number. Carreau nanoliquid flow past a convectively heated expanding surface was numerically studied by Eid, Mahny, Dar, & Muhammad, 2020 using RKF45. A reduction in the mass transfer rate was noted owing to a hike in chemical reaction. Gangadhar, Ramana, Makinde, & Kumar, 2018 explored the consequences of Cattaneo-Christov heat flux on a Carreau fluid past an elongating cylinder. The problem was tackled using the spectral relaxation method and the authors found out that rising magnetic parameter caused an enlargement in the temperature profile. Vinita & Poply, 2020 inspected the response of outer velocity slip flow on an expanding cylinder. The authors noticed shrinkage in the velocity profile due to the increasing velocity slip parameter. Salahuddin, 2020 utilised the Keller box method along with the shooting technique to analyse the Carreau fluid model over an extended cylinder. I. Khan, Malik, Hussain, & Khan, 2017 carried out a study on Carreau nanoliquid flow considering Joule heating over a slanted lengthening cylinder. Salahuddin, Hussain, Malik, Awais, & Khan, 2017 conducted a numerical analysis on the response of chemically reactive species and generalized slip on the MHD Carreau nanoliquid flow induced by a linear expanding cylinder using finite difference method and observed an improvement in the velocity profile with augmenting velocity slip parameter.

2.6 Casson Nanofluid

The fluids whose viscosity alters with stress are termed non-Newtonian fluids. Casson fluid, proposed by Casson, 1959, is a shear thinning fluid that assumes infinite viscosity at zero shear-rate, and vice versa. The rheological equation for an isotropic and incompressible flow of a Casson fluid is given by (see Isa et al., 2017; Suresh Reddy & Panda, 2022):

$$\tau_{ij} = \begin{cases} 2\left(\mu_B + \frac{P_y}{\sqrt{2\pi}}\right) e_{ij} \ , \ \pi > \pi_c \\ \\ 2\left(\mu_B + \frac{P_y}{\sqrt{2\pi_c}}\right) e_{ij}, \ \pi < \pi_c \end{cases} \tag{2.6.1}$$

where where μ_B is plastic dynamic viscosity of the non-Newtonian fluid, P_y is the yield stress of the fluid, τ_{ij} is $(i,j)^{th}$ component of the stress tensor, $\pi = e_{ij}e_{ij}, \ e_{ij}$ is the $(i,j)^{th}$ component of the deformation rate and π_c is a critical value of π based on the non-Newtonian model. Human blood, honey, tomato sauce, jelly, and concentrated fruit juices are a few examples of Casson fluid.

Mukhopadhyay, 2013 observed that the augmentation in Casson parameter suppressed the velocity and enhanced the thermal field. Later, Hussanan, Salleh, Alkasasbeh, & Khan, 2018 extended the work of Mukhopadhyay, 2013 by considering the flow in the presence of Newtonian heating and magnetic field. The consequence of radiation, magnetic field, and non-uniform heat source/sink on the blood-gold Casson nanofluid flow in a slippery curved sheet has been studied by U. Khan, Shafiq, Zaib, Sherif, & Baleanu, 2020. The effectiveness of spherical-shaped gold nanoparticles in the Casson nanofluid flow was pointed out by Nazeer, Irfan, Hussain, & Siddique, 2022. U. Khan, Zaib, Khan, & Nisar, 2021 elucidated the dynamics of blood-based Casson gold nanofluid over a curved elongated/shrinked surface. The negative impact of Casson parameter on the electro-magnetic stagnation flow was noticed by Hussain, Farooq, & Sheremet, 2022.

2.7 Nanofluid Flow Model

Khanafer et al., 2003 proposed a nanoliquid transport model accounting the nanoparticle dispersion. Later, Tiwari & Das, 2007 developed a simpler nanofluid model considering the effective thermophysical properties of a nanofluid. R. Kumar, Kumar, Shehzad, & Sheikholeslami, 2018 utilized the Tiwari-Das nanofluid model to investigate the influence of vibrational rotations and multiple slip conditions on the hydromagnetic nanomaterial flow over an elongating surface. The authors observed a rise in the Nusselt number for augmenting nanoparticle volume fraction. Mustafa, Javed, & Ghaffari, 2016 employed the Tiwari-Das nanoliquid model to mathematically model the magnetohydrodynamic stagnation-point flow of ferro-nanofluid over a spinning disk.

Buongiorno, 2006 proposed a nanofluid model comprising seven slip mechanisms (diffusiophoresis, gravity, Brownian diffusion, fluid drainage, thermophoresis, inertia, and Magnus effect). Among the considered slip mechanisms, only Brownian diffusion and thermophoresis were observed to be significant. Sheikholeslami, Ganji, & Rashidi, 2016 utilized the Buongiorno nanofluid model to investigate the consequence of the magnetic field on the unsteady squeezing flow between two infinite parallel plates. The Bödewadt nanofluid flow employing the Buongiorno nanofluid model was studied by J. Khan, Mustafa, Hayat, & Alzahrani, 2017 with the aid of the Keller-box method. The authors observed that the nanofluid temperature ascended with a larger thermophoretic force. Sadiq, Haider, Hayat, & Alsaedi, 2020 made use of the Tiwari-Das model whereas Hayat, Haider, Muhammad, & Alsaedi, 2020 exercised the Buongiorno nanofluid model to analyze the significance of slip constraints on the Darcy-Forchheimer flow over a spinning disk. Chu et al., 2020 modelled a bioconvective third-grade fluid flow using Buongiorno nanofluid model to investigate the consequence of magnetohydrodynamics (MHD) and activation energy over a lengthening surface.

Buongiorno nanofluid model neglects the nanofluid's effective thermal properties that are dependent on the selected nanoparticle. By including the effective thermophysical characteristics of the nanomaterial in Buongiorno's model, Yang et al., 2013 introduced the modified Buongiorno nanofluid model (MBM). Puneeth, Manjunatha, Madhukesh, & Ramesh, 2021 utilized the RKF-45 scheme and modified Buongiorno nanofluid model to numerically explore the influence of mixed convective hybrid nanomaterial flow past a bidirectional nonlinear expandable sheet. Mahanthesh & Mackolil, 2021 considered the MBM to investigate the consequence of alumina nanomaterial in heat transfer augmentation. The authors established that the random motion and thermophoresis of nanoparticles exhibit a positive effect on the nanomaterial temperature. Rana, Mahanthesh, Mackolil, & Al-Kouz, 2021 investigated the significance of nonlinear convection and aggregation kinematics of nanoparticles on the nanofluid flow (modeled using modified Buongiorno nanofluid model) through a vertical plate.

2.8 Magnetohydrodynamics

Magneto-fluid dynamics (MHD) is the branch in physics which deals with the dynamics of electrically conductive fluids under the influence of a magnetic field. The concept of magnetohydrodynamics was first introduced by Alfvén, 1942. MHD flows have applications in cancer therapy, magnetic cell separation, electromagnetic pump, drug delivery, aeronautics, and magnetic resonance imaging. Sk, Das, & Kundu, 2016 observed that the proficiency of a thermal system can be improved by scheming the strength of the applied magnetic field. An increase in the drag coefficient and a decrease in the heat transfer rate with rise in magnetic parameter values was noted by Jafar, Shafie, & Ullah, 2020. Gholinia, Hoseini, & Gholinia, 2019 numerically investigated the free convective flow of Walter-B nanoliquid over a tilted expanding sheet using RKF45 and noted an increase in the temperature profile due to augmenting magnetic field parameter. Sarkar & Sahoo, 2021 observed a decline in the velocity profiles of the upper solution branch with the augmentation in the intensity of the applied magnetic field. The destructive nature of the magnetic field on the radial and tangential velocity profiles was noted by Upadhya, Devi, Raju, & Ali, 2021. Pal & Mondal, 2018 elucidated the bioconvective MHD nanofluid flow past an exponentially stretching surface and observed a decline in the motile density due to augmenting values of microorganism concentration difference parameter and bioconvection Peclet number. M. A. Kumar, Reddy, Rao, & Goud, 2021 employed a numerical model to investigate the influence of thermal radiation on the nanofluid flow from an infinite vertical plate considering viscous dissipation and magnetic field. It is noted that an augmentation in radiation parameter causes an enhancement in the temperature and velocity profiles.

2.9 Induced Magnetic Field

The magnetic field represents an important characteristic of hydromagnetic problems. In some cases, the magnetic Reynolds number of the flow may not be realistic to be assumed small in magnitude; hence induced magnetic field is not negligible (see O. Koriko, Omowaye, Animasaun, & Bamisaye, 2017). Induced magnetic field (IMF) corresponds to the additional magnetic field that gets induced on electrically conducting fluid when encountered with an external magnetic field caused due to the impact of a larger magnetic Reynolds number. IMF has applications in MRI, glass manufacturing, geophysics, and MHD generators, etc. IMF paired with blood flow plays a decisive role in blood pumps, treatment of cardiac diseases and has many other biomedical applications. Kumari, Takhar, & Nath, 1990 explored the fluid flow and heat transfer over an elongating sheet heeding IMF. Later, the MHD flow over a lengthening sheet subject to an IMF was reinvestigated by F. M. Ali, Nazar, Arifin, & Pop, 2011a. Investigations on entropy generation and IMF effects on Cu and TiO_2 nanofluid using Keller box method are carried out by Z. Iqbal, Maraj, Azhar, & Mehmood, 2017 and observed an improved thermal conductivity for water-based TiO_2 nanofluid when compared with water based Cu nanofluid. Mehmood & Iqbal, 2016 utilized the fifth-order Runge-Kutta method to examine the consequence of induced magnetic field on stagnation point flow of nanofluid involving gyrotactic microorganisms. F. M. Ali, Nazar, Arifin, & Pop, 2011b developed the study of Mahapatra & Gupta, 2002 to analyze the hydromagnetic stagnation point fluid flow over a lengthening sheet subject to an IMF. Later, Junoh et al., 2019 broadened the work of F. M. Ali et al., 2011b to study the hybrid nanoliquid flow characteristics. Gireesha, Mahanthesh, Shivakumara, & Eshwarappa, 2016 numerically analyzed nanofluid stagnation point flow past a stretching surface attending IMF and found out that the induced magnetic field enhances with the intensifying hydromagnetic field. M. S. Iqbal et al., 2020 scrutinized the influence of induced magnetic field on ferrofluid past a vertical stretching surface and observed that velocity profile enhanced for assisting flow with magnetic parameter. Further, Amjad et al., 2020 studied the influence of Lorentz force and induced magnetic field on Casson micropolar nanoliquid over a permeable curved stretching/shrinking surface.

2.10 Electromagnetohydrodynamics

Electromagnetohydrodynamics (EMHD) is the area that concerns the study of dynamics of electrically conducting fluids under the influence of the magnetic and electric fields. EMHD has raised quite an interest over the years due to its versatile application in geophysics, engineering, biomedical engineering, magnetic drug targeting and many others. Z. Shah, Bonyah, Islam, & Gul, 2019 examined the significance of thermal radiation on the EMHD rotating flow of CNTs over a stretching sheet and noticed that the electric parameters ascend the velocity profile whereas the magnetic parameter descends the velocity profile. Daniel, Aziz, Ismail, & Bahar, 2020 analysed the two-dimensional unsteady EMHD nanoliquid flow over a lengthening sheet involving multi-slip and dual stratification effects and noticed that the electric field parameter has a constructive effect on velocity. The effect of EMHD in the nanoliquid flow past a porous Riga plate pertaining gyrotactic microorganism was numerically explored by T. Abbas, Hayat, Ayub, Bhatti, & Alsaedi, 2019. Zhang, Bhatti, & Michaelides, 2020 investigated the EMHD behaviour of a third-grade fluid flowing between a pair of parallel plates utilising a Darcy-Brinkman-Forchheimer model. The authors observed an enhancement in the temperature profile for the augmenting magnetic field parameter. Jakeer & Reddy, 2020 examined the impact of viscous dissipation, heat generation, and slip on the entropy generation in electro-magnetohydrodynamic $Ag-Cu-H_2O$ hybrid nanofluid. In addition, Zainal, Nazar, Naganthran, & Pop, 2021 explored the unsteady EMHD stagnation point flow in a hybrid nanofluid concerning a stretching/shrinking sheet. The double stratification effects on EMHD nanoliquid flow over a lengthening sheet involving Joule heating, viscous dissipation and radiation effects were numerically explored by Daniel, Aziz, Ismail, & Salah, 2017b with the aid of an implicit finite difference scheme. Liu, Jian, & Tan, 2018 conducted an entropy generation analysis of EMHD flow in a curved rectangular microchannel. The authors noticed that the electric field parameter had a positive impact on the entropy generation rate.

2.11 Bioconvection

Bioconvection is a routine mechanism caused by the erratic movement of microorganisms. This phenomenon was first noticed by Wager, 1911 and the term bioconvection was given by Platt, 1961. Bioconvective flow problems find their applications in microbial enhanced oil recovery, toxin removal, targeted drug delivery, food digestion, antibiotics, and bio-microsystems. Kuznetsov & Avramenko, 2004 were among the first few to investigate the stability of a suspension containing microorganisms and small particles. M. Uddin, Khan, Qureshi, & Bég, 2017 employed the Runge-Kutta-Fehlberg method to numerically investigate the impact of thermal and hydrodynamic slip constraints on the water-based bio-nanomaterial containing microorganisms. The authors observed that the augmenting bioconvection Peclet number tends to improve the motile microorganism density number. The consequence of multiple slips on bioconvective flow was studied by Alshomrani, Ullah, & Baleanu, 2020. M. M. Bhatti, Shahid, Abbas, Alamri, & Ellahi, 2020 studied the role of activation energy on a suspension of nanoparticles and microorganisms in a magnetized fluid with the aid of successive local linearization methods. The consequence of hydrodynamic slip and convective boundary conditions on the flow past a lengthening sheet containing microorganisms was examined by Sampath Kumar, Gireesha, Mahanthesh, & Chamkha, 2019. The authors noted a drop in the microbial concentration with a rising bioconvection Peclet number. The outcome of gyrotactic microbes in the nanoliquid flow along a nonlinearly lengthening porous sheet was revealed by Ahmad, Ashraf, & Ali, 2020. Al-Amri & Muthtamilselvan, 2020 explored the significance of thermal radiation, microorganisms, magnetic field, and activation energy on the two-dimensional stagnation point flow of an incompressible nanoliquid and noted an increase in the density of motile microorganisms for larger values of Peclet number. M. Bhatti & Michaelides, 2021 studied the significance of Arrhenius activation energy on the thermo-bioconvection nanofluid flow over a Riga plate and noticed that an augmentation in the bioconvection Rayleigh number weakened the velocity profile. Waqas, Naseem, Muhammad, & Farooq, 2021 observed a shrinkage in the microbial concentration with mounting values of Peclet number. The relevance of three-dimensional bioconvective flow due to an exponentially stretching has been explored by Alqarni, Waqas, Alghamdi, & Muhammad, 2022. The authors noticed that the microbial concentration ascends with microorganism Biot number but descends with Peclet number.

2.12 Stratification

Fluctuations in heat, mass and motile density profiles or the presence of different fluids trigger a formation of layers known as stratification. Alsaedi, Khan, Farooq, Gull, & Hayat, 2017 elucidated the stratification effects of MHD mixed convective nanofluid flow past an elongated surface using homotopy analysis method and observed a decrease in temperature with augmenting thermal stratification parameter. Muhammad, Alamri, Waqas, Habib, & Ellahi, 2021 scrutinized the influence of slip on the bioconvective Carreau nanoliquid flow and observed a decrease in the density of the motile microorganism with augmenting bioconvection Lewis number. A numerical exploration on the impact of swimming gyrotactic microorganisms for hydromagnetic nanofluid through a stretched porous sheet using the Darcy-Forchheimer model was carried out by Shahid, Huang, Bhatti, Zhang, & Ellahi, 2020. The impression of thermal stratification and Marangoni convection on the hybrid nanofluid flow over a spinning disk has been examined by Manzoor, Muhammad, Farooq, & Waqas, 2022. Tlili et al., 2020 analysed the impact of double stratification and partial slip on the hydromagnetic micropolar nanoliquid flow along a stretched surface containing gyrotactic microorganisms and observed a decline in temperature profile due to augmenting thermal stratification values. Ahmad, Nadeem, Muhammad, & Issakhov, 2020 elucidated the effect of double stratification on carbon nanotube (CNT) nanofluid flow and detected a decrease in the nanofluid temperature and volume fraction concerning thermal and solutal stratification parameters, respectively. Further, Ramzan, Riasat, Shah, Kumam, & Thounthong, 2020 examined the impact of thermal stratification parameter on unsteady ethylene glycol-based nanoliquid flow.

2.13 Flow past a Stretching Sheet

Cortell, 2007 explored the heat transfer and viscous fluid flow over an elongating sheet. The analysis was carried out for two cases (a sheet with prescribed surface temperature and for a sheet with constant surface temperature). W. Khan & Pop, 2010 were among the first to study the laminar nanofluid flow problem on a stretching sheet. Rana & Bhargava, 2012 extended the work of W. Khan & Pop, 2010 to investigate the nanofluid flow past a nonlinearly lengthening sheet. The authors noted an increase in nanofluid temperature and a decrease in velocity for mounting values of stretching ratio. Later, Mabood, Khan, & Ismail, 2015 progressed the work of Rana & Bhargava, 2012 by incorporating viscous dissipation and magnetic field effects. Eid, 2020 numerically investigated the heat transfer characteristics of the shape of gold nanoparticles on the blood flow past an exponentially lengthening sheet using Sisko nanofluid and considering the Biot number effect. The highest heat transfer rate was observed by the blade-shaped nanoparticle (blowing case) and the spherical nanoparticles (suction case). Mabood, Ibrahim, Kumar, & Lorenzini, 2020 numerically explained the consequence of thermal radiation, velocity and thermal slip on an inclined MHD Casson nanofluid flow utilizing the Runge-Kutta-Fehlberg method and observed growth in Nusselt number due to augmenting values of Prandtl number. Krishnamurthy, Gireesha, Prasannakumara, & Gorla, 2016 performed a numerical analysis to elucidate the effect of chemical reaction on boundary layer slip flow of nanofluid induced by a nonlinear stretching sheet. The destructive effect of chemical reaction parameter on the nanoparticle concentration profile was observed by S. Ibrahim, Lorenzini, Kumar, & Raju, 2017 and Daniel, Aziz, Ismail, & Salah, 2019.

2.14 Flow over a Rotating Disk

Scientists and researchers follow the studies concerning nanofluid flow due to the rotation of the disk for their practical application in centrifugal filtration, pharmaceuticals, biosensors, medical instruments, microchip pumps, biomedical science, micro-actuators, bio-chromatography, and aerodynamics. Kármán, 1921 was the first to investigate the flow over a rotating disk. Pioneering works on the nanoscale fluid flow over a rotating disk were carried out by Bachok, Ishak, & Pop, 2011 and Turkyilmazoglu, 2014. Mahanthesh, Gireesha, Animasaun, Muhammad, & Shashikumar, 2019 proved the amalgam of $SWCNT - H_2O$ nanomaterial improved the thermal field when compared with the water-based MWCNT nanomaterial. Recently, Shehzad, Mabood, Rauf, Izadi, & Abbasi, 2021 exploited the Runge–Kutta-Fehlberg scheme to elucidate the rheological features of Casson-Maxwell fluids over expandable spinning disk. R. Kumar, Bhattacharyya, Seth, & Chamkha, 2021 studied about magnetite water based nanofluid flow over a rotating disk in the presence of external magnetic field and Arrhenius activation energy using fourth order Noumerov's method and noted that the thermophoresis parameter has a negative impact on heat transfer rate. Doh, Muthtamilselvan, Swathene, & Ramya, 2020 employed the semi-analytical homotopy analysis method (HAM) to examine the effect of homogeneous and heterogeneous reactions on a spinning disk with variable thickness. Hayat, Haider, Muhammad, & Alsaedi, 2017 studied the Darcy-Forchheimer nanofluid flow due to a spinning disk and observed a decrease in the velocity profiles with mounting values of porosity parameter and the inertial coefficient.

2.15 Stagnation Flow

The stagnation point corresponds to the point where the fluid's local velocity is zero. It proposes many applications in engineering, industry, and physiological fluid flows. Hiemenz, 1911 was the first researcher to numerically explore the stagnation-point flow problem. Turkyilmazoglu, 2012 discussed the hydromagnetic stagnation-point due to an expandable whirling disk. R. Kumar, Kumar, Vajravelu, & Sheikholeslami, 2020 explored the stagnation flow of the Casson nanomaterial through Darcy-Forchheimer medium. The authors noted a drop in the velocity profile of Sakiadis flow with the Casson parameter. Mahanthesh, Mackolil, & Shehzad, 2020 statistically surveyed the impact of thermal Biot number and exponential heat source parameter on the heat transfer rate. R. Kumar, Kumar, Sharma, & Sheikholeslami, 2021 employed OHAM to examine the transport of nanomaterial filled in Darcy-Forchheimer medium space. Waini, Ishak, & Pop, 2021 investigated the unsteady stagnation flow of a hybrid nanomaterial on a porous rigid surface and observed an increase in the heat transfer rate with augmenting mass flux parameter. N. Abbas, Malik, Alqarni, & Nadeem, 2020 explored the stagnation-point hybrid nanofluid flow over a slip surface. The authors adopted the Runge-Kutta-Fehlberg method to numerically solve the nonlinear system of differential equations and noted that the velocity is inversely proportional to the velocity ratio parameter. Hafeez, Khan, & Ahmed, 2020 employed the BVP Midrich scheme to numerically survey the hydromagnetic stagnation-point flow of Oldroyd-B nanoliquid.

2.16 Slip Boundary Constraint

The relative movement of the fluid with the boundary is characterized with the aid of slip constraint. Multiple slip corresponds to the case when more than one slip (velocity, thermal, or solutal) condition is considered. Nandeppanavar, Vajravelu, Abel, & Siddalingappa, 2012 employed Wu's velocity-slip model (see Wu, 2008) to investigate the consequence of second-order slip over a lengthening surface. Abdelmalek et al., 2020 utilized HAM to numerically investigate the impact of second-order hydrodynamic-slip parameter and Stefan blowing on the hydromagnetic Casson flow over a linearly extending surface. The dynamics of Casson fluid flow with first-order hydrodynamic-slip over a non-linearly elongating surface was elucidated by Senapati, Parida, Swain, & Ibrahim, 2022. The authors noticed a reduction in the flow velocity with augmentation in the slip-parameter. The ability of the second-order hydrodynamic-slip parameter to increase the Casson nanofluid temperature was pointed out by Obalalu, 2022. Daniel, Aziz, Ismail, &

Salah, 2018 reported that the augmenting velocity slip parameter slows the velocity profile. S. A. Khan, Nie, & Ali, 2020 and Amanulla, Saleem, Wakif, & AlQarni, 2019 noted that multiple slip effects have a positive impact on boundary layer flow. The decrease in the heat transfer rate due to the velocity slip parameter was observed by W. Ibrahim & Negera, 2020. A decrease in the temperature and concentration profile was noted due to the increased thermal and solutal slip parameter values, respectively by Barik, Mishra, Mishra, & Pattnaik, 2020. The temperature and velocity slip effect of Casson nanoliquid flow over a tilted permeable elongating cylinder was examined by Usman, Soomro, Haq, Wang, & Defterli, 2018. The analysis revealed that with increasing slip parameter, Nusselt number shows a decreasing behaviour whereas Sherwood number shows an increasing behaviour.

2.17 Heat Source

Internal heat sources play an important role in various heat transfer applications. A heat source enhances the temperature of working fluid which in return has a considerable effect on the heat transfer rate. The heat generation or absorption parameter plays a key role in medical and industrial fields like cancer therapy, heat pumps, heat exchangers, targeted drug delivery, imaging, and filtration devices. Naramgari & Sulochana, 2016 explored the effect of internal heat generation or absorption parameter on hydromagnetic nanofluid flow over an exponentially stretching sheet. The authors noticed that the heat generation or absorption parameter is capable of enhancing the momentum and thermal boundary layers. The positive impact of nonuniform heat source/sink on the thermal field of a stretching surface was elucidated by Thumma & Mishra, 2020. The impact of an exponential space-based heat source (ESHS) on the Marangoni convection and radiative flow of dusty nanoliquid was explored by Mahanthesh, Gireesha, PrasannaKumara, & Shashikumar, 2017. A positive impact on heat transfer rate and temperature of the dusty nanomaterial is reported due to the presence of the ESHS mechanism. Farooq et al., 2021 explored the impact of ESHS on the bioconvective flow of Carreau nanomaterial over an elongated cylinder and noticed that the temperature profile is directly proportional with the ESHS parameter. The authors concluded that for heating processes the ESHS is deemed to be better suited. The non-uniform heat source (NHS) constitutes a combination of space-dependent heat source (SHS) and temperature-dependent heat source (THS). Mahanthesh, Animasaun, Rahimi-Gorji, & Alarifi, 2019 carried out a comparative analysis on the impact of NHS on dusty-Casson and dusty-Carreau fluid past an elongated surface. A statistical exploration on the effect of NHS over a plate was executed by Mahanthesh, Thriveni, & Lorenzini, 2021. An enhanced thermal field and a declined heat transfer rate was noted by Li et al., 2022 when the magnitude of SHS and THS parameters were augmented.

2.18 Passive Control of Nanoparticles

The boundary constraint when the normal flux of nanoparticles is zero is termed as zero mass flux or passive control of nanoparticles (see Kuznetsov & Nield, 2013). The passive control of the nanoparticles improves the practicality of the model (see Halim, Sivasankaran, & Noor, 2017; Ramly, Sivasankaran, & Noor, 2017; Abdul Halim & Mohd Noor, 2021). I. Uddin et al., 2018 investigated the buoyancy effect on the stagnation point flow with zero mass flux and convective boundary conditions. ur Rehman et al., 2020 elucidated the consequence of thermal stratification and passive control of nanoparticles of Sutterby nanofluid flow over a linearly stretched sheet.

2.19 Thermal Radiation

The transfer of heat by the means of the electromagnetic radiation generated by the thermal motion of particles in matter is called thermal radiation. The phenomenon of thermal radiation has crucial importance in space technology and intense heat processes such as nuclear power plants, gas turbines, gas-cooled nuclear reactors, and space vehicles. Gireesha, Umeshaiah, Prasannakumara, Shashikumar, & Archana, 2020 elucidated the behavior of radiation in MHD three-dimensional Jeffrey fluid flow through a stretching sheet and observed an increment in fluid temperature and nanoparticle concentration with the changes in the radiation parameter. Nasir et al., 2018 implemented the homotopy analysis method (HAM) to address thermal radiation and thermophoresis effects on the three-dimensional rotating nanofluid flow containing single-wall carbon nanotubes (SWCNT). The authors noticed that the nanofluid temperature is an expanding function of radiation parameter. The significant influence of radiation parameters on heat and mass transfer rate is explored by Besthapu, Haq, Bandari, & Al-Mdallal, 2019. Hady, Ibrahim, Abdel-Gaied, & Eid, 2012 investigated the impact of radiation parameter on the viscous flow of a nanofluid over a nonlinearly stretching sheet. The authors observed an improvement in the heat transfer rate with escalating values of thermal radiation parameter. The three-dimensional MHD flow of nanofluid over a nonlinearly stretching sheet in the presence of slip and thermal radiation was elucidated by Mahanthesh, Gireesha, Gorla, & Makinde, 2018. The radiation parameter showcased a positive impact on the temperature profile.

2.20 Newtonian Boundary Constraint

The Newton thermal boundary condition accounts for one of the most common boundary constraints encountered in general practice. The existence of convective heating (or cooling) at the surface due to the surface energy balance is termed Newtonian (or convective) boundary constraint. Seth, Bhattacharyya, Kumar, & Chamkha, 2018 examined about the unsteady hydromagnetic boundary layer flow of a thermally radiating nanofluid considering Navier's velocity slip and Newtonian boundary constraint past a non-linear stretching sheet placed in a porous medium using OHAM. A rise in the nanofluid temperature was noticed for augmenting values of the Biot number. The negative effect of the Biot number on the heat transfer rate was discussed by M. Khan, Irfan, & Khan, 2019 whereas A. Kumar, Tripathi, Singh, & Sheremet, 2021 observed an increase in the Nusselt number.

2.21 Stefan Blowing

The diffusion of nanoparticles (or species) from the lengthening surface to the ambient region creates a blowing effect. This blowing effect, derived from the Stefan problem, is dissimilar from the mass injection or blowing resulting from transpiration on a permeable surface. This was initially studied by Spalding, 1954. Fang & Jing, 2014 revealed the improvement in the flow field with increasing values of blowing parameter whereas a decrease in velocity profile with improving Stefan blowing parameter was presented by B. Ali, Hussain, Abdal, & Mehdi, 2020. The consequence of Stefan blowing and thermo-hydrodynamic slip over a linearly lengthening sheet employing Lie group analysis was elucidated by Rana, Shukla, Bég, & Bhardwaj, 2021. The flow was mathematically modeled using the modified Buongiorno model. Gowda, Kumar, Prasannakumara, Nagaraja, & Gireesha, 2021 utilized the Runge-Kutta-Fehlberg 45 (RKF45) procedure to numerically explore the ferromagnetic fluid flow over a flat lengthening sheet considering the magnetic dipole effect. Bég, Kabir, Uddin, Izani Md Ismail, & Alginahi, 2021 utilized the Chebyshev spectral collocation method to appraise the effect of Stefan blowing and microorganisms on the swirling nanomaterial flow from a whirling disk.

2.22 Statistical Techniques

The inclusion of statistical techniques like regression analysis, response surface methodology and sensitivity analysis for scrutinizing physical quantities like drag coefficients, heat and mass transfer rates has been amply exercised by the researchers recently. Statistical tools like multiple linear regression, correlation, probable error and slope of linear regression prove to be a better methodology in analysing the relationship between the effectual parameters and the dependent variables. The pertinent flow parameters are taken as the independent variables and physical quantities (like drag coefficient, mass transfer rate or heat transfer rate) are chosen as the dependent variable. Response Surface Methodology (RSM) analyses the collaborative outcome of influential parameters (independent variables) on the physical quantity of interest (response or dependent variable). Sensitivity analysis, on the other hand, measures the extent and nature of dependency exhibited by the independent variables on the response variable. Thriveni & Mahanthesh, 2021 utilized RSM and sensitivity analysis to statistically measure the consequence of effectual parameters on the Nusselt number of hybrid nanoliquid flow in a micro-annulus. The authors noted that the quadratic radiation parameter is positive sensitive towards the Nusselt number. Pordanjani et al., 2019 examined the influence of heating length, Richardson number, and Hartmann number on the entropy generation, Nusselt number, and Bejan number of a hybrid nanomaterial in a square diagonal cavity with the aid of RSM and sensitivity analysis. A positive sensitivity for Hartmann number on the Bejan number and a negative sensitivity for Hartmann number on the averaged Nusselt number were observed. Mackolil & Mahanthesh, 2021 performed a sensitivity analysis on the reduced Nusselt number considering magnetic parameter, thermal radiation parameter, and nanoparticle volume fraction. The authors delineated the dominance of the thermal radiation parameter on the reduced Nusselt number. Shafiq, Sindhu, & Khalique, 2020 employed sensitivity analysis on the density of motile microorganisms and Nusselt number considering Lewis number, Brownian motion variable, and thermophoresis number as the influential parameters on an exponentially stretched surface. The authors noted that the rate of heat transfer of the nanomaterial is maximum when a larger value of Brownian motion and smaller values of Lewis number and thermophoresis aspect are considered. Further, the significance of the applied magnetic field on the Nusselt number and surface friction coefficient in the forced convective nanomaterial flow past a wedge was revealed by Vahedi, Pordanjani, Raisi, & Chamkha, 2019 by employing RSM and sensitivity analysis methods.

2.23 Need for the Study

Based on the literature review, the following gaps have been identified.

- The bioconvective stagnation point flow of CNT over a stretching sheet considering induced magnetic field, microorganisms and stratification effects has not been a topic of study.
- The dynamics of water conveying single-wall carbon nanotubes and magnetite nanoparticles subject to induced magnetic field has not yet been studied.
- The effect of multiple slip, spherical and non-spherical (cylinder, platelet, and blade) nanoparticles on the stagnation point flow of silver-blood nanofluid in the presence of an induced magnetic field has not yet been studied.
- The stratification effects of electromagnetohydrodynamic bioconvective CNT nanofluid flow past a stretching sheet has not yet been studied.
- No attempt to study the consequences of multiple slip on hydromagnetic convective Carreau nanoliquid flow over an elongating cylinder has been carried out.
- The significance of magnetic field and stratification constraints on the bioconvective stagnation-point flow over a rotating stretchable disk has not been considered yet.
- No attempt to study the MHD flow of a nanomaterial over a nonlinearly elongated surface in the presence of radiation and exponential heat source using the modified Buongiorno model and passive control of nanoparticles has been carried out.

- The dynamics of bioconvective magnetized nanomaterial flow over a nonlinearly elongated surface with Stefan blowing and Newtonian boundary constraints has not been considered yet.
- The dynamics of electro-magnetohydrodynamic Casson nanomaterial flow over a nonlinearly stretched surface with second-order hydrodynamic-slip and non-uniform heat source has not yet been studied.