# Chapter 9

# Conclusive remarks and future scope

Various mathematical models were used in the thesis to numerically and statistically examine the flow of hydromagnetic nanofluid. The study examines the applicability of nanofluids by including the impacts of various parameters on different hydromagnetic fluids. In the thesis, aggregation kinematics and nanoparticle shape effects are taken into account. Utilizing three-dimensional surface plots and statistical techniques, a study on the augmentation of the heat transfer and optimization of the drag coefficient is undertaken. The use of graphs allows for the comparison of numerical and statistical values. Following is a summary of the overall findings.

- Hall current and injection/suction parameter plays a crucial role in amplifying the velocity profile.
- The temperature and velocity profiles are directly proportional to the heat source parameter, $S$.
- Angle of inclination, $\alpha$ has a constructive effect on the velocity profiles.
- The volume fraction of the nanoparticles, $\phi$ enhances the concentration profiles but reduces the temperature and velocity profiles.
- The Soret effect has a destructive impact on concentration profiles.
- Heat source and hall current has a negative impact on skin friction.
- An increase of 0.982513 per unit $S$ (heat source) is noted due to the impact of heat source on Nusselt number.

- Soret number has a negative impact (a decrease of 1.853334359 per unit $S_o$) on Sherwood number.
- The velocity profiles are directly proportional to the viscosity ratio parameter in shear thinning case and inversely proportional in shear thickening case.
- Weissenberg number enhances the velocity profiles in case of shear thickening fluids and retards the velocity profiles for shear thinning fluids.
- An exponential increase is observed in the temperature profile due to an increase in Biot number, heat generation/absorption and thermophoresis parameters.
- Increase in the stretching ratio parameter improves the Y directional velocity profile.
- The concentration profile is enhanced and depleted with increasing thermophoresis and Brownian motion effects, respectively.
- The regression models are found to be in synchronization with the numerical results for the chosen values of parameters.
- Exponential space-based heat source (ESHS) and linear heat source (LHS) parameters exhibit a constructive behaviour on the temperature profile.
- Slip effect decreases the velocity and temperature profiles.
- Weissenberg number exhibits a differing nature on the velocity profile based on the nature of fluid; velocity is reduced when $n < 1$ and increased when $n > 1$.
- Velocity slip increases the drag coefficient whereas Hartmann number decreases the drag coefficient.
- Heat transfer rate lowers with ESHS, LHS and temperature slip parameters.
- Mass transfer rate is inversely proportional to concentration slip parameter.
- Nusselt number has been faultlessly estimated using multiple linear regression.
- The aggregation kinematic aspect enhances the temperature field due to the improved thermal conductivity of the nanofluid.

- The velocity retards due to variation in Hartmann number and an opposite trend is exhibited for temperature. It is due to the generated opposing force, namely the Lorentz force.
- The temperature profile enhances with more thermal radiation and exponential heat source effects. Physically, these parameters contribute more energy to the fluid
- The surface drag force is an increasing function of quadratic thermal convection aspect.
- Maximum heat transfer occurs at the highest level of quadratic thermal convection and nanoparticle volume fraction parameters.
- The heat flux is more sensitive to the inclination angle when compared to other parameter values. This sensitivity augments at a rate 0.5094% for the increment in $R$.
- An accurate quadratic model is estimated for the wall heat flux with $\mathcal{R}^2 = 99.98\%$.
- The wall shear stress decrements by 41.1388 % when the inclination of the plate is changed from $60^0$ to $75^0$.
- The $x$-directional velocity descends with the Forchheimer number and hydrodynamic slip parameter.
- The $y$-directional velocity ascends with the stretching parameter.
- The suction case exhibits lowered temperature and velocity profiles in correspondence with the injection case.
- The Biot number and the volume fraction of copper nanoparticles have a constructive effect on the hybrid nanoliquid temperature.
- The heat transfer rate is higher for the suction case in comparison with the injection case.
- The heat transfer rate is higher for lower values of magnetic field parameter and higher values of Biot number and volume fraction of copper nanoparticles.

- The drag coefficients increase with hydrodynamic slip parameter and decrease for higher values of magnetic field and porosity parameters.
- Higher drag coefficients are observed in the case of injection when compared with the suction case.
- A commendable agreement is noted between the numerical and statistical results.
- Radial and azimuthal velocities demote with an increment in magnetic field due to the presence of Lorentz force.
- Radial velocity and surface drag decrease with augmentation in Reiner-Rivlin fluid parameter. It is due to an elevation in the cross-viscosity coefficient.
- The temperature profile increases due to both temperature and space-dependent heat sources. An opposite trend is noted in the heat transfer rate.
- Joule heating has a positive influence on the thermal boundary layer. The heat transfer rate lowers with an increment in the Eckert number.
- Hartmann number, Reiner-Rivlin fluid parameter, and thermal slip parameter show a negative response with heat transfer coefficient.
- The heat transfer sensitivity towards the Hartmann number decreases at the rate of 0.2267% and the sensitivity towards the Reiner-Rivlin fluid parameter decreases at the rate of 0.0554% when thermal slip is incremented.
- The azimuthal velocity is inversely proportional to the hydrodynamic slip parameter.
- The nanofluid temperature ascends with the hydrodynamic slip parameter and descends with the thermal slip parameter.
- The nanofluid temperature is an increasing function of nanoparticle shape factor whereas the nanofluid concentration is a reducing function of nanoparticle shape factor.
- The heat transfer rate ascends with an increase in the volume fraction of alumina nanoparticle.

- The highest drag is exhibited by platelet-shaped alumina nanoparticles followed by cylinder-, brick-, and sphere-shaped alumina nanoparticles.

The basic concepts and knowledge of fluid mechanics and modelling problems are essential for analyzing a system working in a fluid medium. Nanofluids enhances the conventional fluid (e.g., water, kerosene, Ethylene glycol, and oil) with nanotechnology that made a drastic change in Engineering, industry medical, and Economic fields. Theoretical models lessen risk, conserve resources, and add more concepts to the experimental design. Hydromagnetic stagnation point flow over a stretchable disk is in initial stage. There are so many work to be done in the area. The mathematical models described in this work can be expanded in the following ways in the future.

- Entropy generation in MHD convective nanofluid flow with more than one nanoparticles.

- Optimising the drag coefficient of MHD convective nanofluid flow with microorganisms.

- Enhancing heat transport of MHD convective nanofluid flow in the presence of electric field and non linear Boussinesq approximation.

- To study convective flow in the presence of induced magnetic field.

# Publications in journals and presentations

## Publications:

1. Sabu, A. S., Mathew, A., Neethu, T. S., & George, K. A. (2021). Statistical analysis of MHD convective ferro-nanofluid flow through an inclined channel with hall current, heat source and soret effect. Thermal Science and Engineering Progress, 22, 100816. https://doi.org/10.1016/j.tsep.2020.100816

2. Sabu, A. S., Areekara, S., & Mathew, A. (2021). Statistical analysis on three-dimensional MHD convective Carreau nanofluid flow due to bilateral nonlinear stretching sheet with heat source and zero mass flux condition. Heat Transfer, 50(4), 3641-3660. https://doi.org/10.1002/htj.22045

3. Sabu, A. S., Areekara, S., & Mathew, A. (2021). Effects of multislip and distinct heat source on MHD Carreau nanofluid flow past an elongating cylinder using the statistical method. Heat Transfer, 50(6), 5652-5673. https://doi.org/10.1002/htj.22142

4. Sabu, A. S., Mackolil, J., Mahanthesh, B., & Mathew, A. (2022). Nanoparticle aggregation kinematics on the quadratic convective magnetohydrodynamic flow of nanomaterial past an inclined flat plate with sensitivity analysis. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 236(3), 1056-1066. https://doi.org/10.1177/09544089211056235

5. Sabu, A. S., Areekara, S., & Mathew, A. (2022). Regression analysis on MHD Darcy-Forchheimer hybrid nanoliquid flow over an elongated permeable sheet in a porous medium with hydrodynamic slip constraint: a realistic two-phase

modified Buongiorno model. Waves in Random and Complex Media, 1-24. https://doi.org/10.1080/17455030.2022.2086318

6. Sabu, A. S., Mackolil, J., Mahanthesh, B., & Mathew, A. (2022). Numerical study of Reiner-Rivlin nanoliquid flow due to a rotating disk with Joule heating and non-uniform heat source using Bulirsch-Stoer algorithm. Waves in Random and Complex Media, 1-23. https://doi.org/10.1080/17455030.2022.2111476

7. Sabu, A. S., Wakif, A., Areekara, S., Mathew, A., & Shah, N. A. (2021). Significance of nanoparticles' shape and thermo-hydrodynamic slip constraints on MHD alumina-water nanoliquid flows over a rotating heated disk: The passive control approach. International Communications in Heat and Mass Transfer, 129, 105711. https://doi.org/10.1016/j.icheatmasstransfer.2021.105711.

## Presentations:

1. Presented a paper entitled "MHD nanofluid flow past a stretching sheet containing different shapes of nanoparticles with thermal radiation and Chemical reaction", in the 28th International conference (Virtual) of forum for Interdisciplinary Mathematics, Synergies in Computational, Mathematical, Statistical and Physical sciences (FIM 28, SCMSPS 2020), organized by FIM Stella Maris College (Autonomous),Chennai, and Sri Sivasubramaniya Nadar College of Engineering (Autonomous) Tamilnadu during 23-27 November 2020.

2. Presented a paper entitled "MHD nanofluid flow containing various shapes of nano particles in a rotating porous channel with chemical reaction and radiation", in the international conference on Mathematics 2018, organized by department of Mathematics, St Thomas College (Autonomous) Thrissur, Kerala and International multidisciplinary research foundation (IMRF), during 29-30 June 2018.

3. Presented a paper entitled " Radiative MHD flow of nano fluids in a vertical channel with hall current" in the International conference on Mathematical Impacts in science and technology (BIT MIST-2017), organised by Department of Mathematics, Bannari Amman Institute of technology (Autonomous), Sathyamangalam, Tamilnadu during 17-18 November 2017.