IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 1, July 2026

Impact Factor: 8.2

Study of Entropy Generation and Chemical Reaction Analysis of Nanofluid Flow Over a Non-Linear Stretched Surface

Rakesh Kumar[1] and Naresh Kumar Sharma[2]

Associate Professor, Department of Chemistry, Govt. P. G. Nehru College Jhajjar, Haryana[1]

Professor, Department of Chemistry, Lords University, Alwar, Rajasthan[2]

rakesh.pasrija@gmail.com

Abstract: *This research investigates the entropy generation and chemical reaction characteristics in the flow of nanofluids over a non-linear stretched surface. Nanofluids, composed of nanoparticles suspended in a base fluid, exhibit enhanced thermophysical properties and are gaining widespread interest in heat transfer applications. The study focuses on the effects of various physical factors, including velocity and temperature gradients, on entropy generation, along with the influence of chemical reactions on the flow dynamics. The governing partial differential equations (PDEs) are transformed into a set of ordinary differential equations (ODEs) using similarity transformations. A numerical solution is obtained using the shooting method along with the Runge-Kutta scheme. The results provide insights into the effects of nanoparticles, stretching parameters, chemical reactions, and entropy generation on the thermal performance and efficiency of the nanofluid flow.*

Keywords: Entropy Generation, Non-linear Stretched Surface, Chemical Reaction

I. INTRODUCTION

Flow behavior over stretching surfaces has attracted many authors due to its wide area of industrial and manufacturing applications like artificial fibers, manufacturing of metallic sheets, petroleum industries, metal spinning, polymer processing etc. The flow caused by the stretching surface was initially investigated by Crane [1]. After that, Gupta and Gupta [2] and Dutta et al. [3] gained new heights of Crane [1] work by comprising the analysis of mass and heat transportation using many different aspects. Yoon et al. [4] reported the comparison between theoretical and experimental results by considering a thin metal stretching sheet. Vajravelu and Rollins [5] investigated the heat transfer behavior in viscoelastic fluid over a stretching sheet. The nanofluid also comes in existence when we add a small quantity of nano-sized particles which are also called ultrafine particles to the base fluid. Recently, study of nanofluid has much more importance due to its uses, properties and applications in different research areas. Choi and Eastman [6] introduced the concept of nanofluid. The main characteristic of nanofluid is to increase the thermal conductivity of base fluid [7].

In recent years, MHD flow has gained attention due to its controllable heat transfer rate and great utilizations in various industrial areas and manufacturing processes. Hayat et al. [8] studied the impact of MHD on heat and flow transportation over stretching surfaces. On stretching surfaces, a stagnation point micropolar MHD nanofluid flow was numerically investigated by Anwar et al. [9]. After that Shawky et al. [10] studied Williamson nanofluid towards a stretching sheet and he reported that the increment in non-Newtonian parameter increases both the Skin friction coefficient as well as the rate of heat transfer. Vajravelu and Cannon [11] investigated the fluid flow characteristics on non-linear stretching sheet. Also, a mixed convection magnetohydrodynamic nanofluid flow along with entropy analysis on a non-linear stretching sheet has been represented by Matin et al. [12]. Das [13] studied the partial slip effect on nanofluid past a permeable non-linearly stretching sheet. Powell-Eyring MHD nanofluid flow having variable thickness past a non-linear stretched surface was interpreted by Hayat et al. [14]. Jain and Choudhary [15] examined the influence of Soret and Dufour

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, July 2026
Impact Factor: 8.2

numbers with MHD flow in presence of chemical reactions. Siddheshwar and Mahabaleshwar [16] studied the problem of heat and flow transportation on non-linear stretching sheet with suction/injection.

Furthermore, the non-linear effect over stretching surfaces under different physical circumstances has also been examined by researchers in [17]-[26]. No study has been done so far to analyze the combined effect of outer velocity with non-linear stretching in a Casson nanofluid. In present study, we analyzed the combined effect of outer velocity with non-linear stretching sheet in a MHD Casson nanofluid. In this analysis, we observe that an inverted boundary layer is formed in velocity profiles when we take the outer velocity parameter greater than one. Also, outer velocity has a great impact on the rate of heat transportation and nanoparticle concentration. The outcomes of Current study reveals that as non-linearity in the stretching sheet increases, velocity decreases for outer velocity less than one and increases for outer velocity greater than one.

II. MATERIALS AND METHODS

2-D incompressible boundary layer flow with nanofluid towards a non-linear stretching sheet has been considered. This non-linear behavior produces a flow and sheet is stretched with stretching velocity $\boldsymbol{u_w = ax^N}$, where $\boldsymbol{a}$, $\boldsymbol{x}$ and $\boldsymbol{N}$ denotes a constant, stretching surface coordinate and non-linear stretching parameter respectively. Figure 1 depicts the physical model of the present problem. In this physical configuration system, $\boldsymbol{T_w, C_w, T_\infty}$ and $\boldsymbol{C_\infty}$ represents temperature at the sheet, nanoparticle volume fraction at surface, ambient temperature attained and ambient nanoparticle volume fraction serially. The induced magnetic field is very small comparative to apply magnetic field so is neglected. The basic governing equations for nanofluid in terms of Cartesian coordinates are described as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\tau\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}-K_1(C-C_\infty) \tag{4}$$

Initial boundary conditions are given as:

$$\begin{gathered} u_w = ax^N, \quad v=0,\; T=T_w,\; C=C_w \;\; at\; y=0 \\ u\to 0,\quad C\to C_\infty, T\to T_\infty \;as\; y\to\infty \end{gathered} \tag{5}$$

Here vertical and horizontal velocities are represented by v and u, respectively. Also ν, σ, B, ρ_f, U denotes the kinematic viscosity, velocity slip parameter, magnetic field intensity, density of base fluid, outer velocity, $\alpha_m=\frac{k_m}{(\rho c)_f}$ is the thermal diffusivity, a is a positive constant, $\tau=\frac{(\rho c)_p}{(\rho c)_f}$ defines a proportion of heat capacities of nanofluid to base fluid, ρ_p is density of particles, D_T is thermophoretic diffusion coefficient and D_B is Brownian diffusion coefficient.

DOI: 10.48175/IJARSCT-37639

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, July 2026
Impact Factor: 8.2

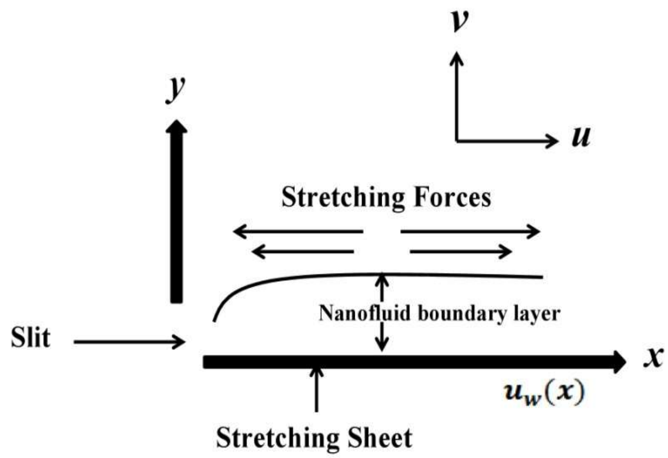

Figure 1: Physical model of problem

Equations (1) to (4) with boundary conditions (5) are transformed using similarity variables

$$\eta = y\sqrt{\frac{a(N+1)}{2\nu}}x^{\frac{N-1}{2}}, u = ax^N f'(\eta), v = -\sqrt{\frac{a\nu(N+1)}{2}}x^{\frac{N-1}{2}}\left(f(\eta) + \left(\frac{N-1}{N+1}\right)\eta f'(\eta)\right) \quad (6)$$
$$\theta(\eta) = \frac{T-T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

Substituting equation (6) into equations (2) to (4), we have

$$f''' + ff'' - \left(\frac{2N}{N+1}\right)(f'^2) = 0 \quad (7)$$
$$\theta'' + Pr(f\theta' + Nb\,\theta'\phi' + Nt\,(\theta')^2) = 0 \quad (8)$$
$$\phi'' + Lef\phi' + \frac{Nt}{Nb}\theta'' - \gamma\phi = 0 \quad (9)$$

The transformed boundary conditions are

$$\left.\begin{array}{l} f(0) = 0, f'(0) = 1, \theta(0) = 1, \phi(0) = 1 \\ f'(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0 \end{array}\right\} \quad (10)$$

where $(\,)'$ denotes derivative w.r.t η. Here Nt, Nb, Le and Pr represents the thermophoresis parameter, Brownian motion parameter, Lewis number and Prandtl number respectively and these fluid parameters are given by:
$Nt = \frac{D_T(T_w - T_\infty)}{T_\infty\, \nu}$, $Nb = \frac{D_B(C_w - C_\infty)}{\nu}$, $\gamma = \frac{K_1 Le}{\alpha}$, $Le = \frac{\nu}{D_B}$ and $Pr = \frac{\nu}{\alpha}$

Also, local Sherwood number and local Nusselt number are respectively defined as:

$$Sh_x = \frac{xq_m}{D_B(C_w - C_\infty)} \text{ and } Nu_x = \frac{xq_w}{k(T_f - T_\infty)} \quad (12)$$

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 1, July 2026

Impact Factor: 8.2

where q_m and q_w are mass flux and heat flux at the stretching surface serially

$$q_m = -D_B(C_w - C_\infty)\mathrm{x}^{\frac{N-1}{2}}\sqrt{\frac{\mathrm{a}(\mathrm{N}+1)}{2\nu}}\,\phi_0'(0) \tag{13}$$

$$q_w = -k(T_w - T_\infty)\mathrm{x}^{\frac{N-1}{2}}\sqrt{\frac{\mathrm{a}(\mathrm{N}+1)}{2\nu}}\,\theta_0'(0) \tag{14}$$

The volumetric rate of entropy generation is

$$S_G = \frac{k}{T_\infty}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2\right]$$

The first term indicates the entropy generation due to heat transfer across a finite temperature difference, A dimensionless number for entropy generation rate N_S is defined as the ratio of the local volumetric entropy generation rate S_G to a characteristic entropy generation rate $(S_G)_0$.
For a prescribed boundary condition the characteristic entropy generation rate is

$$(S_G)_0 = \frac{k\,\Delta T^2}{x^2 {T_\infty}^2}$$

Hence, the entropy generation number is

$$N_S = \frac{S_G}{(S_G)_0}$$

Using Above equations, it can be expressed as

$$N_S = \left(\theta'(0)\right)^2$$

Numerical procedure

The system of non-linear differential equations (7)-(9) are not solved analytically due to extremely non-linear behaviour. To solve this system of non-linear differential equations (7)-(9) together with boundary conditions (10), we adopt Runge Kutta Fehlberg approach (numerical procedure) with shooting technique.

The above system of differential equations is solved using shooting technique with RKF method. Figure 2 display the flow chart of numerical procedure adopted above.

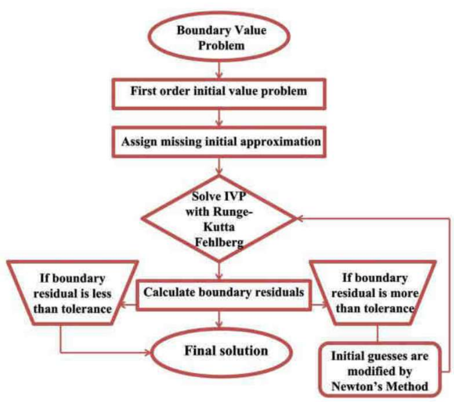

Figure 2: Flow chart of Numerical procedure

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, July 2026
Impact Factor: 8.2

III. RESULTS AND DISCUSSION

In current study, non-linear differential equations (7)-(9) with boundary conditions (10) are computed numerically.

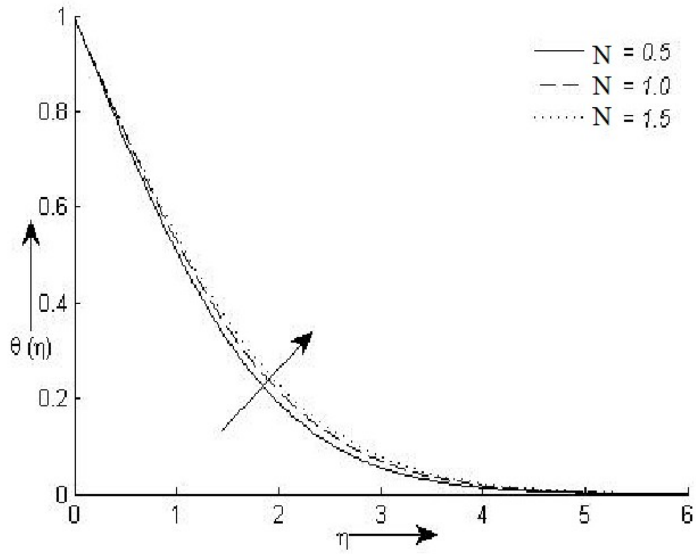

Figure 3: Temperature profile for various N

Figure 3 depicts the variation in temperature profiles for different values of the non-linear parameter N. It is evident from the figure that an increase in N leads to a corresponding increase in the fluid temperature throughout the boundary layer. This behaviour can be physically interpreted by considering the effect of non-linear stretching on the thermal boundary layer. As N increases, the stretching rate of the surface becomes more intense in a non-linear fashion. This enhanced stretching action generates additional frictional heating due to increased shear forces within the fluid, which contributes to a rise in the local fluid temperature, especially near the wall region.

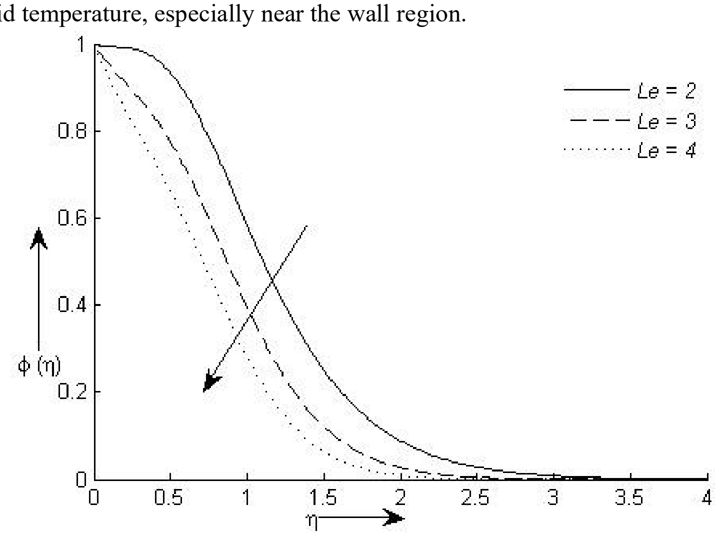

Figure 4: Concentration profile for various Le

Figure 4 illustrates the effect of the Lewis number Le on the concentration profiles within the boundary layer. From the figure, it is evident that as the Lewis number increases, the concentration of the fluid decreases throughout the concentration boundary layer. With increasing Le, the ability of species to diffuse away from the surface diminishes. This

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, July 2026
Impact Factor: 8.2

leads to a thinner concentration boundary layer and a more rapid decay of concentration away from the surface. Consequently, the concentration profiles within the boundary layer decrease more sharply with increasing Le.

IV. CONCLUSION

This study represents influence of outer velocity with mass and heat transportation on Casson nanofluid past a nonlinear stretching sheet

- Temperature increases with increase in N.
- Concentration decreases with increase in Le.

Present study finds great application in insulation of wires, manufacturing of tetra packs (e.g. water packs, milk packs, juice packs, etc.), production of glass fibers, fabrication of various polymers and plastic packs, rubber sheets etc. The quality of desired product depends on the external magnetic field, rate of stretching and composition of material used.

REFERENCES

1. L. J. Crane, "Flow past a stretching plate," *Journal of Applied Mathematics and Physics (ZAMP)*, vol. 21, no. 4, pp. 645–647, Jul. 1970, doi: 10.1007/BF01587695.
2. P. S. Gupta and A. S. Gupta, "Heat and mass transfer on a stretching sheet with suction or blowing," *Can. J. Chem. Eng.*, vol. 55, no. 6, pp. 744–746, Dec. 1977, doi: 10.1002/cjce.5450550619.
3. B. K. Dutta, P. Roy, and A. S. Gupta, "Temperature field in flow over a stretching sheet with uniform heat flux," *International Communications in Heat and Mass Transfer,* vol. 12, pp. 89-94, 1985.
4. B. B. Yoon, R. S. Rao, and N. Kikuchi, "Sheet stretching: A theoretical-experimental comparison," *International Journal of Mechanical Sciences*, vol. 31, no. 8, pp. 579–590, Jan. 1989, doi: 10.1016/0020-7403(89)90065-9.
5. K. Vajravelu and D Rollins, "Heat Transfer in a Viscoelastic Fluid over a Stretching Sheet," *Journal of Mathematical Analysis and Applications,* vol. 158, pp. 241-255, Jun. 1991.
6. S. U. S. Choi and J. A. Eastman, "Enhancing thermal conductivity of fluids with nanoparticles," pp. 1-9, Jan. 1995.
7. Y. Menni, A. J. Chamkha, G. Lorenzini, N. Kaid, H. Ameur, and M. Bensafi, "Advances of Nanofluids in Solar Collectors - A Review of Numerical Studies," *MMEP*, vol. 6, no. 3, pp. 415–427, Sep. 2019, doi: 10.18280/mmep.060313.
8. T. Hayat, M. Qasim, and S. Mesloub, "MHD flow and heat transfer over permeable stretching sheet with slip conditions," *Int. J. Numer. Meth. Fluids*, vol. 66, no. 8, pp. 963–975, Jul. 2011, doi: 10.1002/fld.2294.
9. M. S. Anwar and A. Rasheed, "Simulations of a fractional rate type nanofluid flow with non-integer Caputo time derivatives," *Computers & Mathematics with Applications*, vol. 74, no. 10, pp. 2485–2502, Nov. 2017, doi: 10.1016/j.camwa.2017.07.041.
10. H. M. Shawky, N. T. M. Eldabe, K. A. Kamel, and E. A. Abd-Aziz, "MHD flow with heat and mass transfer of Williamson nanofluid over stretching sheet through porous medium," *Microsystem Technologies*, vol. 25, no. 4, pp. 1155–1169, Apr. 2019, doi: 10.1007/s00542-018-4081-1.
11. K. Vajravelu and J. R. Cannon, "Fluid flow over a nonlinearly stretching sheet," *Applied Mathematics and Computation*, vol. 181, no. 1, pp. 609–618, Oct. 2006, doi: 10.1016/j.amc.2005.08.051.
12. M. H. Matin, M. R. H. Nobari, and P. Jahangiri, "Entropy Analysis in Mixed Convection MHD flow of Nanofluid over a Non-linear Stretching Sheet," *JTST*, vol. 7, no. 1, pp. 104–119, 2012, doi: 10.1299/jtst.7.104.
13. K. Das, "Nanofluid flow over a non-linear permeable stretching sheet with partial slip," *Journal of the Egyptian Mathematical Society*, vol. 23, no. 2, pp. 451–456, Jul. 2015, doi: 10.1016/j.joems.2014.06.014.
14. T. Hayat, I. Ullah, A. Alsaedi, and M. Farooq, "MHD flow of Powell-Eyring nanofluid over a non-linear stretching sheet with variable thickness," *Results in Physics*, vol. 7, pp. 189–196, 2017, doi: 10.1016/j.rinp.2016.12.008.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, July 2026
Impact Factor: 8.2

15. S. Jain and R. Choudhary, "Soret and Dufour Effects on Thermophoretic MHD Flow and Heat Transfer Over a Non-linear Stretching Sheet with Chemical Reaction," *International Journal of Applied and Computational Mathematics*, vol. 4, no. 1, pp. 1-27, Feb. 2018, doi: 10.1007/s40819-018-0481-2.
16. P. G. Siddheshwar and U. S. Mahabaleshwar, "Flow and Heat Transfer to a Newtonian Fluid Over Non-linear Extrusion Stretching Sheet," *Int. J. Appl. Comput. Math*, vol. 4, no. 1, pp. 1-24, Feb. 2018, doi: 10.1007/s40819-017-0466-6.
17. Z. Abbas and T. Hayat, "Stagnation slip flow and heat transfer over a nonlinear stretching sheet," *Numerical Methods for Partial Differential Equations*, vol. 27, no. 2, pp. 302–314, Mar. 2011, doi: 10.1002/num.20523.
18. B. S. Dandapat and S. Chakraborty, "Effects of variable fluid properties on unsteady thin-film flow over a non-linear stretching sheet," *International Journal of Heat and Mass Transfer*, vol. 53, no. 25–26, pp. 5757–5763, Dec. 2010, doi: 10.1016/j.ijheatmasstransfer.2010.08.007.
19. R. Cortell, "Viscous flow and heat transfer over a nonlinearly stretching sheet," *Applied Mathematics and Computation*, vol. 184, no. 2, pp. 864–873, Jan. 2007, doi: 10.1016/j.amc.2006.06.077.
20. P. Rana and R. Bhargava, "Flow and heat transfer of a nanofluid over a nonlinearly stretching sheet: A numerical study," *Communications in Nonlinear Science and Numerical Simulation*, vol. 17, no. 1, pp. 212–226, Jan. 2012, doi: 10.1016/j.cnsns.2011.05.009.
21. M. Almakki, H. Mondal, and P. Sibanda, "Entropy generation in MHD flow of viscoelastic nanofluids with homogeneous-heterogeneous reaction, partial slip and nonlinear thermal radiation," *Journal of Thermal Engineering*, pp. 327–345, Apr. 2020, doi: 10.18186/thermal.712452.
22. Poply V., Vinita, "Analysis of Outer Velocity and Heat Transfer of Nanofluid Past a Stretching Cylinder with Heat Generation and Radiation," In: Singh P., Gupta R.K., Ray K., Bandyopadhyay A. (eds) Proceedings of International Conference on Trends in Computational and Cognitive Engineering. Advances in Intelligent Systems and Computing, vol 1169. Springer, Singapore. https://doi.org/10.1007/978-981-15-5414-8_18
23. B. Pekmen Geridönmez, "Numerical simulation of natural convection in a porous cavity filled with ferrofluid in presence of magnetic source," *Journal of Thermal Engineering*, vol. 4, no. 2, pp. 1756–1769, Dec. 2017, doi: 10.18186/journal-of-thermal-engineering.369169.
24. V. Poply, P. Singh and A. K. Yadav, "A study of temperature-dependent fluid properties on MHD free stream flow and heat transfer over a non-linearly stretching sheet," *Procedia Engineering*, vol. 127, pp. 391 – 397, 2015.
25. P. Singh and V. Poply, "Impact of free stream velocity and variable heat flux over a permeable stretching surface," *International Journal of Applied Engineering Research*, vol. 10, pp. 69-76, 2015.