The International Journal of Engineering and Science (IJES)
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805
|| Pages || PP 55-60 || 2020 ||

Effect of Arrhenius activation energy and dual stratifications on the MHD flow of a Maxwell nanofluid with viscous heating

Sandhya G[1], Sreelakshmi K[2], Sarojamma G[3,*]
[1,3]Department of Applied Mathematics, Sri PadmavatiMahilaVisvavidyalayam, Tirupati - 517502, Andhra Pradesh, India
[2]Department of Applied Mathematics, Sri Venkateswara Vedic University, Tirupati - 517502, Andhra Pradesh, India
*Corresponding author Sarojamma G

--***ABSTRACT***--

Exploration of the coupled action of Arrhenius function, viscous heating, radiative thermal energy and dual stratifications on the mixedconvection flow of a Maxwell based nano fluid over a linearly stretched surface with effecting a magnetic force andconsidering the impact ofDarcy–Forchheimer and porous medium is the focus of this investigation. The transport equations of the problem are deduced to a set of nonlinear conjugated equations with the aid of suitable scaling analysis. Application of the BVC45 method to these equations conceded the computational solution. Maxwell variabledwindled down the flow. Activation energy as wellas parameter pertaining to temperature difference augmented concentration.

KEYWORDS;-Activation energy, Dual stratifications, nonNewtonian based nanofluid, Viscous heating

I. INTRODUCTION

The innovative efforts of Choi [1] in developing nanofluids brought a revolution in the thermal energy transport. They are extensively used for every effective cooling in various industries such as microelectronics, transportation, manufacture etc., and for removal of hotspots in various components used in computers, power electronics, and telecommunication [2]. In space technology and nuclear system nanofluids are used to have high temperatures and very high cooling [3, 4].

Stratification involves layerformation as a consequent of fluctuate temperatures, soluteconcentration or with fluids having variant density. Dual stratification is noticed when both processes pertaining to thermal and solute take place at the same instant. Srinivasacharya and RamReddy[5] addressed the impact of both stratificationson transport phenomena in a micromaterial effecting the porous matrix. Sreelakshmiand Sarojamma[6] examined the two stratification in stagnationpoint flow related toMaxwellmaterial with radiative heat. In a subsequent paper[7] they investigated the doubly stratified slip flow considering the effects of microrotation and radiation.

Mass transfer takes place due to the concentration differences occurring in the species. Mass transmissionalong with any chemical action is of significant importance due its wide range of its diligences in chemical engineering, food litigated industries, etc. Further, activation of energy (AE) is said to be the least possible energy essential to engender a chemical reaction (CR). The pioneering study involving Arrhenius AE was carried out by Bestman [8] to examine the rate of mass transmission in a viscous fluid flowing in a tube placed in a vertical directionthrough a porous medium. Recently, Zeeshan et al [9] discussed the interaction of AE and CR in a flow between two horizontal channel implementing the convective conditions on the wall for temperature and nano particle volume fraction. Rashidi et al [10] analysed the 3-D flow in a rotating frame considering the effect of non-Darcy porous medium as well as the AE. Girisha et al[11]investigated the dispersion of nano particles in a Casson fluid to realise the impact of binary CR and AE.

In this research work, we analysed the oncoming of AE in a non-Darcy Maxwell based nanofluid flow driven by aelongated sheet implementing the of dual stratification, thermal radiation, magnetic force and viscous dissipation.

II. MATHEMATICAL FORMULATON

We have cogitated the Arrhenius AE in the MHD non-Darcy flow of an incompressible Maxwell nanofluid accomplished due to a surface stretched with a linear velocity $u_w = bx$.Fig.1designates thegeometry corresponds to flow. The coupling effect of thermal and solutal stratification and radiative heat transfer is incorporated in the investigation.The influence of a magnetic force of intensityB_0 applied in the transverse direction on the flow is considered.

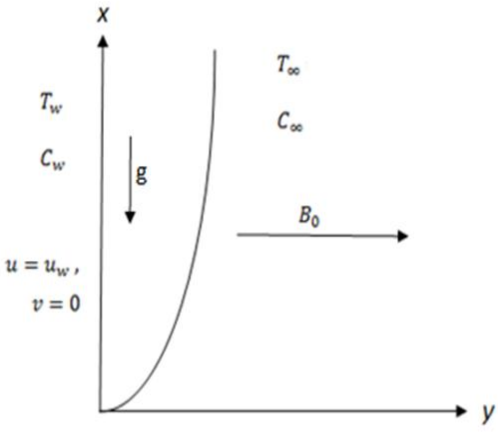

Fig.1 Flow geometry

Following Buongiorno model [12], the equations of the flow are given below:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (1)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \lambda\left(u^2\frac{\partial^2 u}{\partial x^2} + v^2\frac{\partial^2 u}{\partial y^2} + 2uv\frac{\partial^2 u}{\partial x \partial y}\right) = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho}\left(u + \lambda v\frac{\partial u}{\partial y}\right) + g\beta_T(T - T_\infty) + g\beta_C(C - C_\infty) - \frac{\nu}{k'}u - Fu^2, \quad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma^* T_\infty^3}{3\rho c_p k^*}\frac{\partial^2 T}{\partial y^2} + \frac{\rho^* c_p^*}{\rho c_p}\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) + \frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2, \quad (3)$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} - k_r^2(C - C_\infty)\left(\frac{T}{T_\infty}\right)^n e^{\left(-\frac{E_a}{k^\circ T}\right)}, \quad (4)$$

Boundary conditions:

$$u = u_w,\ v = 0, T = T_w = T_0 + m_1 x, C = C_w = C_0 + n_1 x \text{ at } y = 0, \quad (5)$$

$$u \to 0 T \to T_\infty = T_0 + m_2 x,\ C \to C_\infty = C_0 + n_2 x \text{ as } y \to \infty, \quad (6)$$

III. METHOD OF SOLUTION

The scalingtransformations given below are inclosed [13]:

$$u = bxf'(\eta),\ v = -\sqrt{b\nu}f(\eta),\ \eta = \sqrt{\frac{b}{\nu}}y,\ \theta(\eta) = \frac{T - T_\infty}{T_w - T_0},\ \phi(\eta) = \frac{C - C_\infty}{C_w - C_0}, \quad (7)$$

Substitution of equation (7) into the governing equations (2) – (4) afford the non-linear ordinary differential equations mentioned below:

$$f''' + ff'' - (1 + F_r)f'^2 + \beta(2ff'f'' - f^2 f''') - M(f' - \beta ff'') + R(\theta + N\phi) - K_p f' = 0, \quad (8)$$

$$(1 + \tfrac{4}{3}Nr)\theta'' + Pr\left(f\theta' - f'\theta - \varepsilon_1 f' + Nb\theta'\phi' + Nt\,\theta'^2 + Ecf''^2\right) = 0, \quad (9)$$

$$\phi'' + LePr(f\phi' - f'\phi - \varepsilon_2 f') + \frac{Nt}{Nb}\theta'' - Le\,\mathrm{Pr}\,\Lambda\,(1 + \delta\theta)^n\,\phi\, e^{\left(-\frac{E}{1+\delta\theta}\right)} = 0. \quad (10)$$

The boundary conditions (5) and (6) become:

$$f(0) = 0,\ f'(0) = 1,\ \theta(0) = 1 - \varepsilon_1,\ \phi(0) = 1 - \varepsilon_2, \quad (11)$$

$$f'(\infty) \to 0, \theta(\infty) \to 0,\ \phi(\infty) \to 0. \quad (12)$$

The three quantities ,coefficients of solutalandthermal transmission and local wall friction are itemized as

$$Sh_x = \frac{xq_m}{D_B(C_w - C_\infty)},\quad Nu_x = \frac{xq_w}{k(T_w - T_\infty)}, C_f = \frac{2\tau_w}{\rho u_w^2}, (13)$$

where the wall shear stress τ_w, the surface heat flux q_w and mass flux q_m are given by

$$\tau_w = \mu(1 + \beta)\left(\frac{\partial u}{\partial y}\right)_{y=0},\quad q_w = -k\left(\frac{16\,T_\infty^3\sigma^*}{3\,k^* k} + 1\right)\left(\frac{\partial T}{\partial y}\right)_{y=0},$$

$$q_m = -D_B\left(\frac{\partial C}{\partial y}\right)_{y=0}, \quad (14)$$

Equations (14) and (13), result in

$$\frac{1}{2}C_f Re_x^{1/2} = (1 + \beta)f''(0), \quad (15)$$

$$Nu_x Re_x^{-1/2} = -\left(1 + \frac{4}{3}Nr\right)\left(\frac{1}{1 - \varepsilon_1}\right)\theta'(0), \quad (16)$$

$Sh_x Re_x^{-1/2} = -\left(\frac{1}{1-\varepsilon_2}\right)\phi'(0),$ (17)

Where $Re_x = \frac{u_w x}{\nu}$ is the local Reynolds number.

The equations in (8) - (10) are highly non-linear coupled ODEs and solving them for analytical solutions is not possible. Hence, they are tackled along with BC given in (11) and (12) by the standard Runge-Kutta method coupled with the elegant shooting procedure.Utilizing MATLAB software their computational solutions are derived. The validity of the procedure is ensured by collating the values of $-f''(0)$ obtained by Hayat et al.[14], Sadiq and Hayat [15] when $F_r = K_p = R = N = 0$ and for the particular case of a Newtonian material for distinct values of magnetic field parameter (M). The data tabulated in Table 1 reveals that the currentoutcomes areextremely close to them.

M	Hayat et al. [14]	Sadiq and Hayat [15]	Present results
0.0	1.00000	1.00000	1.00000
0.2	1.01980	1.01980	1.01980
0.5	1.11803	1.11803	1.11803
0.8	1.28063	1.28063	1.28063
1.0	1.41421	1.41421	1.41421
1.2	1.56205	1.56205	1.56205
1.5	1.80303	1.80303	1.80303

Table 1Comparison values of $-f''(0)$ for different values of M when $F_r = k_p = R = N = 0$ in Newtonian case.

IV. RESULTS AND DISCUSSION

The objective of this communication is to examine the response of the flow variables of the Darcy-Forchheimer Maxwell nanofluid to the action of Arrhenius function (AF), dual stratification, magnetic force and radiative thermal energy.

Fig. 2 illustrates the response of velocity to the Maxwell parameter (β) and magnetic force parameter (M). Asβ is directly related to relaxation time, elevated values of βreflectsmoretime of relaxation which causes the fluid heavily viscous leading to the dwindling in velocity. In the nonmagnetic case, velocity steadily falls.Attrition ofvelocity is noticed prominently close to the boundary on account of resisting nature of the Lorentzforce.

Fig. 3 is the velocity graphs displaying its relationship with the Forchheimer number (F_r) and permeability parameter (K_p). In the porous medium $(F_r = 0.0)$, the velocity drops rapidly from its preassigned value near the surface and a fall as we move away from the boundary and eventually mergingwith value of free stream. When $F_r = 0.5,$ the velocity pattern is alike. The increased drag offered by the porous matrixfosters a reduction in speed. As $F_r$rises more reduction in the velocity persists A declination is found in velocity for higher values of K_p owing to the Darcy resistance. Increased permeability parameter resists the flow and thus velocity is curtailed.

Fig. 4 reveals that in the absence of viscous heating $(Ec = 0)$ a small undershoot of temperature is found for $\varepsilon_1 = 0.4$ owing to extreme thermal variation. This may be due to the fact that as the free stream temperature T_∞rises in the current stream direction, the flow approaching from below tends to have temperature lesser than its local value and thus negative temperature occurs. Increased values of ε_1 lead to significant reduction of temperature closer to the surface. When $Ec = 1$ the temperature increases for all values of ε_1 and an overshoot of temperature is noticed near the surface.

It is clear from Fig. 5 that the nanoparticle concentration shows a subjugation with an increment in ε_2. In a similar fashion to that of the effect of ε_1 on temperature, an undershoot in nanoparticle concentration takes place when $\varepsilon_2 = 0.7$ and this undershoot improves with ε_2. The reaction of nanoparticle concentration in respect of Λ is to show a rapid diminishing action consideringΛ. Excessdilution in concentration prevails with augmentedΛ. Due to the extremeCR rate the nanoparticle concentration is diminished.

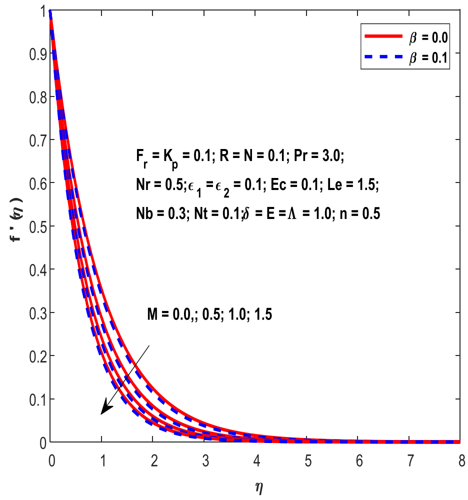

Fig. 2: Variation of M and β on $f'(\eta)$

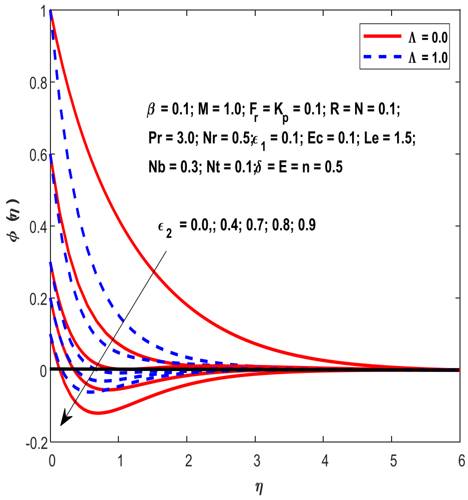

Fig. 5: Variation of ε_2 and Λ on $\phi(\eta)$

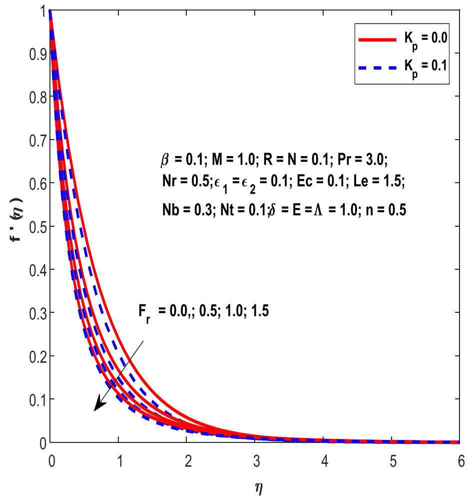

Fig. 3: Variation of F_r and K_p on $f'(\eta)$

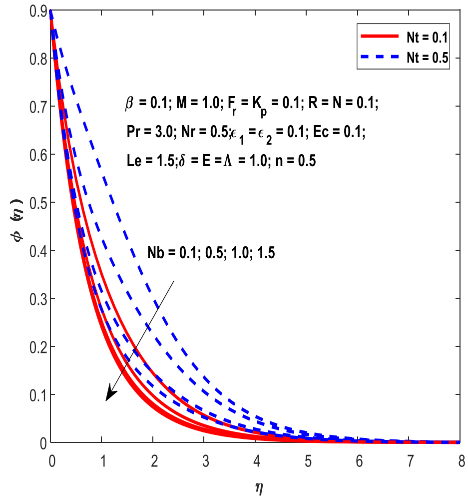

Fig. 6: Variation of Nb and Nt on $\phi(\eta)$

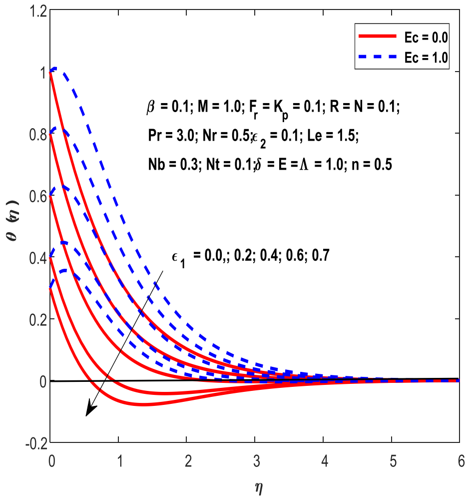

Fig. 4: Variation of ε_1 and Ec on $\theta(\eta)$

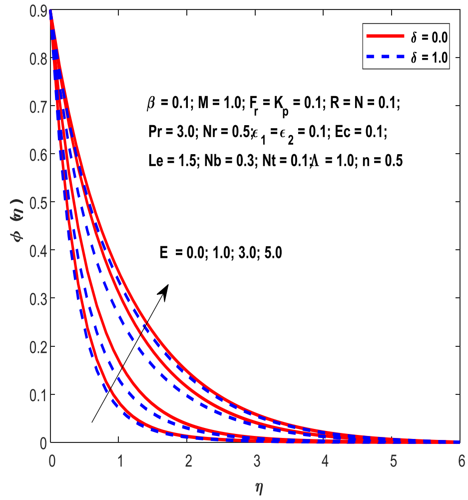

Fig. 7: Variation of E and δ on $\phi(\eta)$

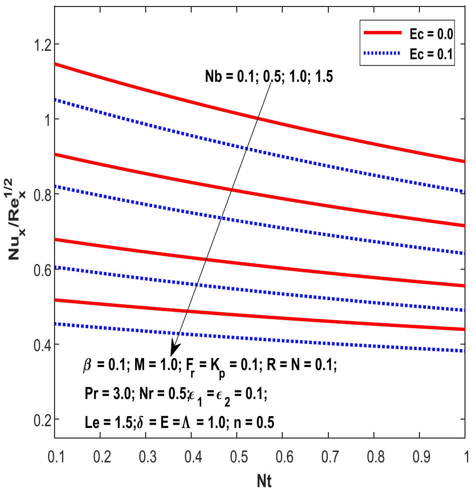

Fig. 8: Variation of Nt, Nb and Ec on $Nu_x Re_x^{-1/2}$

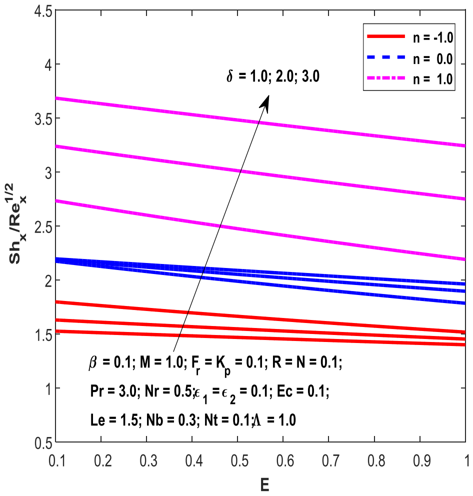

Fig. 9: Variation of δ, n and E on $Sh_x Re_x^{-1/2}$

Fig. 6 reveals the response of nanoparticle concentration to Brownian motion (Nb) and thermophoresis (Nt) parameters. It is clear that increased values of both Nb and Ntare lower the nanoparticleconcentration.

Fig.7 displays the reaction of nanoparticle concentrate to AE (E) and variable of temperature difference (δ). Large δsolicit a dilution in the concentration. The AE (E) concentrates moreas a result of function of Arrhenius. Increased values of E enhance the concentration nominally close to surface and a significant augmentation persists in far away from wall ultimately satisfying the conditions at far infinity . This may be concluded that the activation ofAF is responsible for the stimulation of the generative CR.

From Fig. 8 it may be concluded that the Nusselt number linearly diminishes with thermophoresis variable. Nband Eckert number show a diminishing action on Nusselt number. Fig. 9 projects the response of Sherwood number varyingthe parameter of AE (E) from 0.1 to1.0 when $n = 0$ and altering δ from 1-3. When $n = -1$ the Sherwood number decreases linearly with E. As δ increases Sherwood number augments. When $n = 0$ the reduction in Sherwoodnumber is noticed for $E \geq 0.2$. When$n \geq 1$ the reduction ismore, for lesser valuesof E.

V. CONCLUSION

Mixed convective flow of the Darcy-Forchheimer Maxwell nanofluid flow driven by the elongated sheet including the influence of double stratification and activation energy is addressed.The study indicates that mellower values of Maxwell and magnetic parameters brought a diminution in velocity. Undershoot of temperature (concentration) occurs for stronger thermal (solutal) stratification while Eckert number has a reversal effect. Thermophoresis and microconvection parameters lower the concentration while activation energy has an opposite effect.Brownian motion, thermophoresis parameters and Eckert number cause a reduction in Nusselt number.Sherwood number decreases with AE variable while it increases with temperature difference variable.

REFERENCE

[1]. S. U. S. Choi, “Enhancing Thermal Conductivity of Fluids with Nanoparticles”, In: D. A. Siginer and H. P. Wang, Eds., Developments and Applications of Non-Newtonian Flows, ASME, New York, 66: 99-105, 1995.

[2]. S. Lee and S. U. S. Choi, “Application of metallic nanoparticle suspensions in advanced cooling systems”, In 1996 International Mechanical Engineering Congress and Exhibition. Atlanta, USA, 1996.

[3]. S. M. You, J. H. Kim, and K. H. Kim, “Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer”, Appl. Phys. Lett., 83: 3374-3376, 2003.

[4]. P. Vassallo, R. Kumar, and S. D’Amico, “Pool boiling heat transfer experiments in silica–water nano-fluids”, Int. J. Heat Mass Transf., 47: 407-411, 2004.

[5]. D. Srinivasacharya, Ch. RamReddy,” Heat and mass transfer by natural convection in a doubly stratified non-Darcy micropolar fluid″, Int. Comm. Heat Mass Transf., 37: 873-880, 2010.

[6]. K. Sreelakshmi, G. Sarojamma,“Heat transfer analysis in the non-orthogonal flow of anon-Newtonian nanofluid with non-linear thermal radiation”, Transactions of A. Razmadze Mathematical Institute 172: 606-618, 2018

[7]. G. Sarojamma, R. Vijaya Lakshmi, K. Sreelakshmi , K. Vajravelu, “Dual stratification effects on double-diffusive convective heat and mass transfer of a sheet-driven micropolar fluid flow” , Journal of King Saud University – Sci., 32, 366–376, 2020.

[8]. A.R. Bestman, “Radiative heat transfer to flow of a combustible mixture in a vertical pipe”, Int. J. Energy Res., 15: 179-184, 1991.

[9]. A. Zeeshan, N. Shehzad, R. Ellahi, “Analysis of activation energy in Couette-Poiseuille flow of nanofluid in the presence of chemical reaction and convective boundary conditions”,Results in Physics, 8 : 502–512, 2018

[10]. Saida Rashid, Tasawar Hayat, Sumaira Qayyum, Muhammad Ayub, Ahmed Alsaedi, "Threedimensionalrotating Darcy–Forchheimer flow with activation energy", Int. Journal of Numerical Methods for Heat & Fluid Flow, 29 : 3, 935-948, 2019

[11]. Gireesha B.J., M. Archana, B. Mahanthesh, Prasannakumara B.C., "Exploration of activationenergy and binary chemical reaction effects on nano Casson fluid flow with thermal and exponentialspace-based heat source", Multidiscipline Modeling in Materials and Structures, 15 : 1, 227-245, 2019

[12]. J. Buongiorno, "Convective Transport in Nanofluids", J. Heat Transf., 128: 240-250, 2006.

[13]. K. Sreelakshmi, G. Sarojamma, and D. Makinde, "Dual Stratification on the Darcy-Forchheimer Flow of a Maxwell Nanofluid over a Stretching Surface", Defect and Diffusion Forum, 387: 207-214, 2018.

[14]. T. Hayat, M. I. Khan, M. Farooq, A. Alsaedi, M. A. Waqas, and T. Yasmeen, "Impact of Cattaneo–Christov heat flux model in flow of variable thermal conductivity fluid over a variable thicked surface", Int. J. Heat Mass Transf., 99: 702-710, 2016.

[15]. M. A. Sadiq, and T. Hayat, "Darcy–Forchheimer flow of magneto Maxwell liquid bounded by convectively heated sheet", Results in Phys., 6: 884-890, 2016.