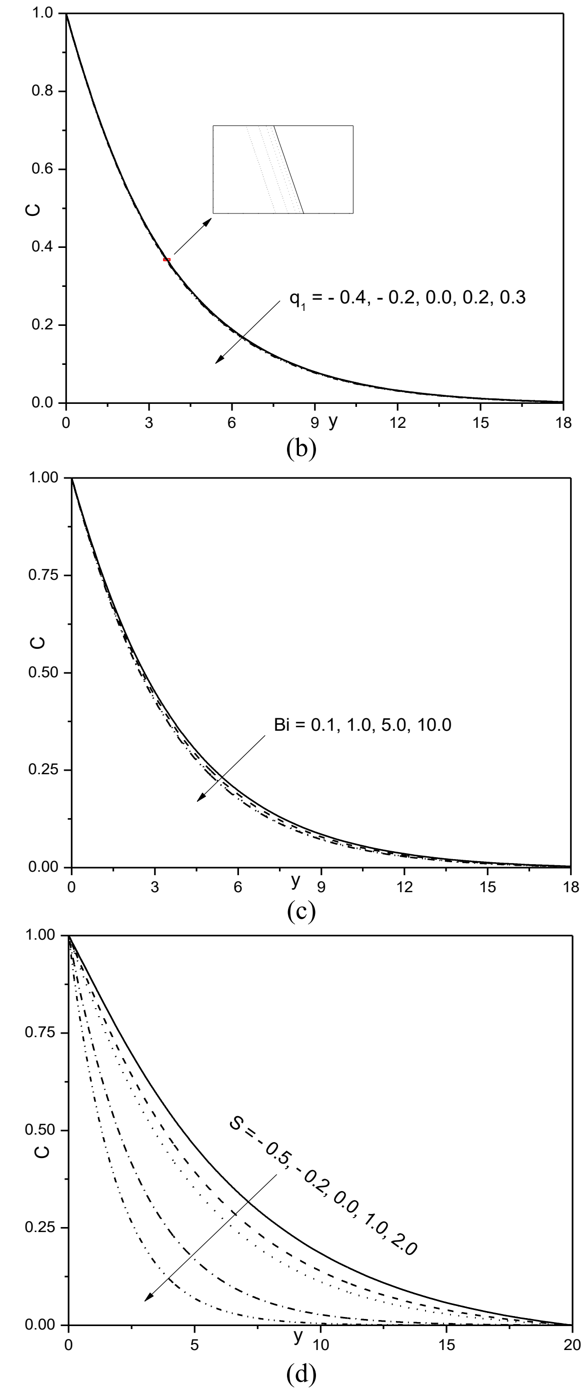
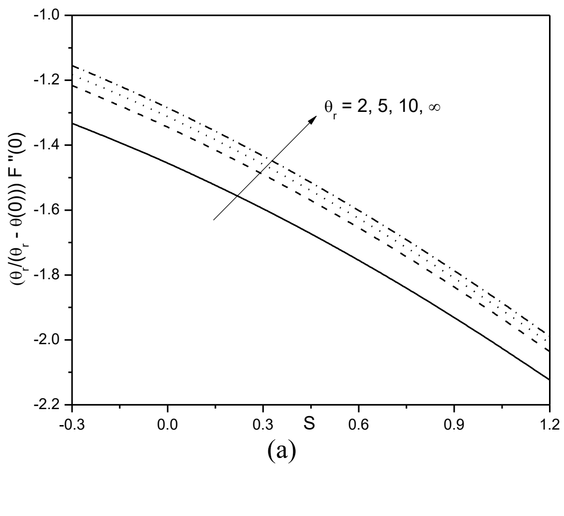


Figure 4. Influence of (a) θ_r, (b) q1, (c) Bi and (d) S on C



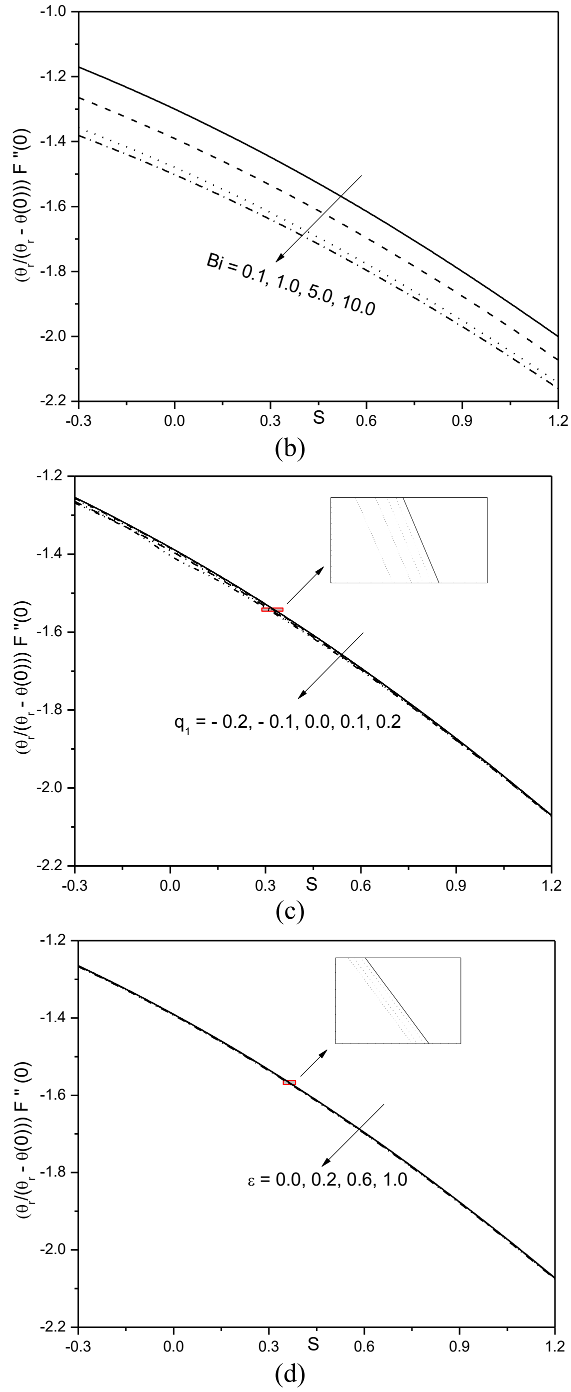
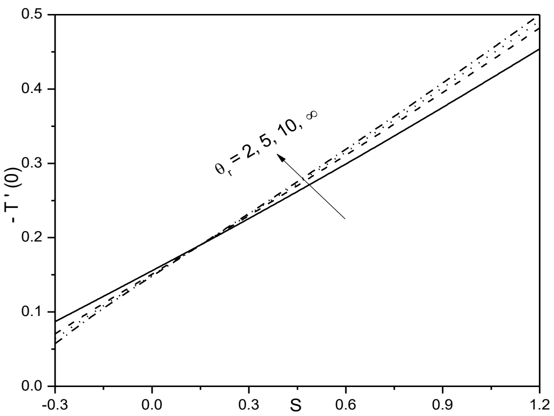


Figure 5. Influence of (a) θ_r, (b) Bi, (c) q1 and (d) ε on (θ_r /(θ_r – T(0))) F´´(0)

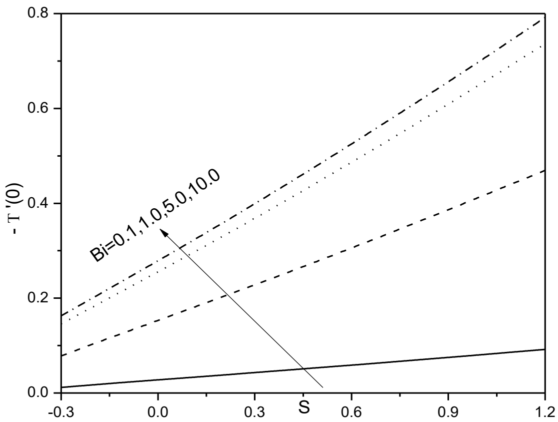
The variation of skin-friction coefficient with varying values of θ_r, Bi, q_1 and ε against S is presented in the Figs. (5a) - (5d). It is evident from the Fig. (5a) that increase in the value of viscosity parameter increases the skin-friction. Hence, decrease in the fluid velocity. Increase in the value of Bi, diminishing the skin-friction and increases the fluid velocity in the bounady layer as shown in the Fig. (5b). While, there is negligible effect of q_1 and ε on skin-friction as depicted in the Figs. (5c) and (5d). It is obvious from these figures that skin-friction reducing very slightly with increase in the value of heat source and thermal conductivity parameters. Further, due to wall suction the momentum boundary reduces and hence, skin-friction is reducing with increasing in the value of S.

Behaviour of rate of heat transfer for several values of θ_r,

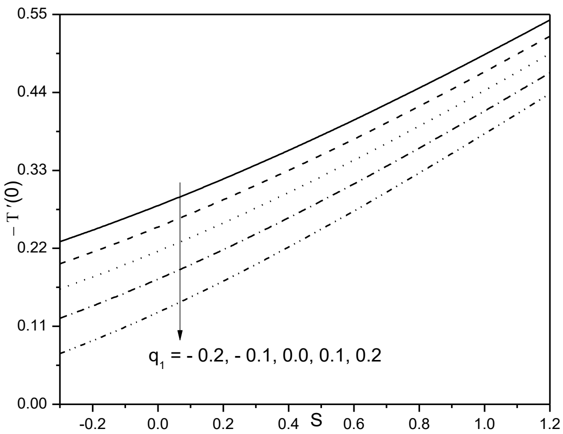
Bi, q_1 and ε against S is portrayed in the Figs. (6a) – (6d). The rate of heat transfer from the sheet to the fluid is diminishing with raise in θ_r as shown in the Fig. (6a). Further, it is noticed that the trend is reversed. ie., heat transfer from the sheet to the fluid is increasing with increase in the values of S and θ_r. Figure (6b) narrates that the raise in Bi enhances the rate of heat transfer from the sheet to the fluid. Increase in the value of the heat generation parameter leads to a decrease in the local Nusselt number. This is because the heat generation mechanism will increase the fluid temperature near the surface and thus temperature gradient at the surface decreases, thereby decreasing the heat transfer at the sheet as shown in the Fig. (6c). On the other hand, rate of heat transfer reduced with raise in the value of ε as shown in the Fig. (6d). While, it is clear from the figures that the rate of heat transfer increasing with wall suction. Further, the wall suction has the tendency to cut down the thermal boundary, and hence, maximum heat transfer at the surface of the boundary as shown in the Figs. (6a) – (6d).



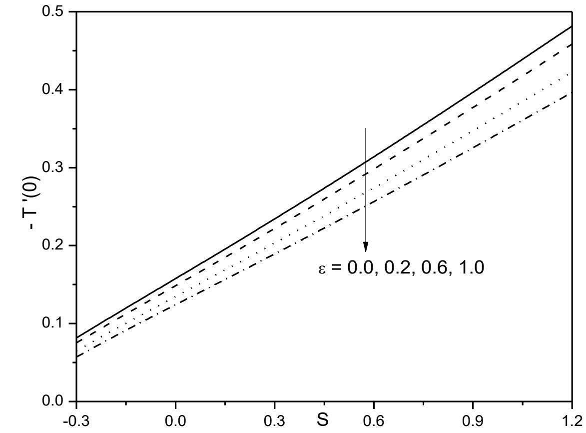
(a)



(b)



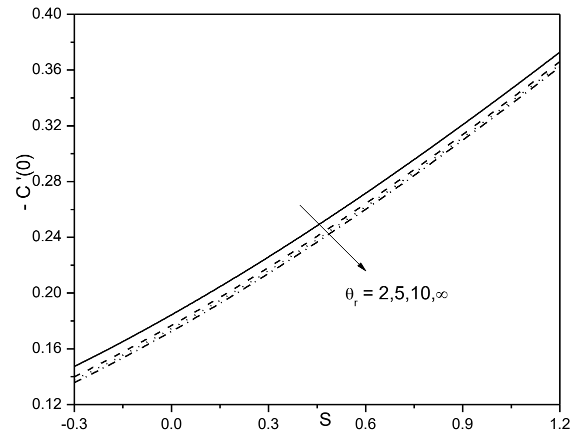
(c)



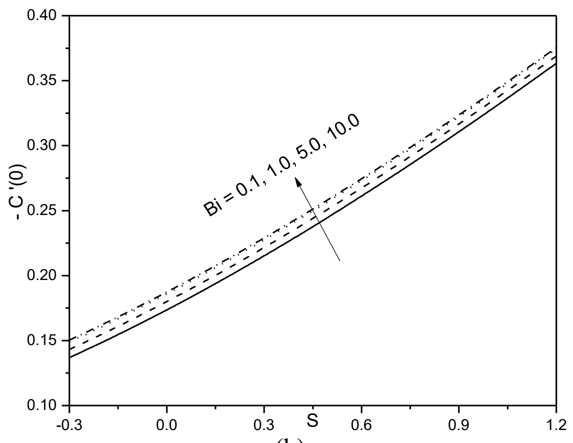
(d)

Figure 6. Influence of (a) θ_r, (b) Bi, (c) q1 and (d) ε on $-T'(0)$

For distinct values θ_r, Bi, q_1 and ε, the fluctuation of rate of mass transfer is graphitised against S through the Figs. (7a) – (7d). Increasing the value of viscosity parameter θ_r, the rate of mass transfer is diminishing as shown in the Fig. (7a). Whereas, from the Fig. (7b), it is obvious that the rate of mass transfer is increasing with raise in Bi. On the other hand, there's mild effect of heat source and thermal conductivity parameters on the rate of mass transfer as depicted in the Figs. (7c) and (7d). It is obvious from these figures that the rate of mass transfer is slightly enhanced with raise in q_1 and ε. Further, it is noticed that the wall suction increases the rate of mass transfer as it reduces the concentration boundary layer thickness.



(a)



(b)

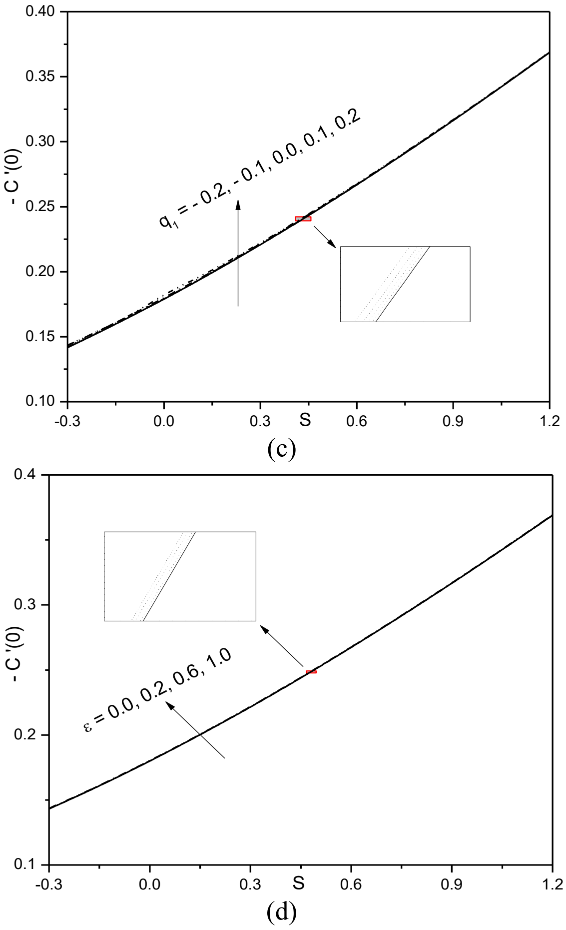


Figure 7. Influence of (a) θ_r, (b) Bi, (c) q_1 and (d) ε on $-C'(0)$

5. CONCLUSIONS

The significance of variable visocity and thermal conductivity on the flow over a sheet stretching exponentially, in presence of heat source is studied. Successive linearization procdure along with the Chebyshev spectral method is used to solve the governing equations.

- The velocity is increasing with increase in the values of heat source parameter and Biot number. But, decreasing with variable viscosity and suction parameters.
- Temperature of the fluid enhances, raising the values of thermal conductivity, heat source parameters and Biot number and decreases with suction parameter.
- Concentration of the fluid increases with increase in viscosity parameter and decreasing with heat source, suction parameters and Biot number.
- Skin-friction is increasing with viscosity parameter and decreasing with thermal conductivity, heat source, suction parameters and Biot number.
- The rate of heat transfer increased with a raise in Bi and decreased with increase in the value of thermal conductivity and heat source parameters. But, dual nature is observed with increase in the value of viscosity parameter.

The rate of mass transfer is reduced with raise in the value of viscosity parameter and increased with increase in the values of Bi, thermal conductivity and heat source parameters.

REFERENCES

[1] Sakiadas BC. (1961). Boundary-layer equations for two-dimensional and axisymmetric flow. A. I. Ch. E. Journal 7(1): 26-28.

[2] Sakiadas BC. (1961). The boundary layer on a continuous flat surface. A. I. Ch. E. Journal 7(2): 221-225.

[3] Crane LJ. (1970). Flow past a stretching plate. Journal of Applied Mathematics and Physics 21(4): 645-647.

[4] Kumaran V, Ramanaiah G. (1996). A note on the flow over a stretching sheet. Acta Mechanica 116: 229-233.

[5] Magyari E, Keller B. (1999). Heat and mass transfer in the boundary layers on an exponentially stretching continuous surface. Journal of Physics D: Applied Physics 32(5): 577-585.

[6] Sajid M, Hayat T. (2008). Influence of thermal radiation on the boundary layer flow due to an exponentially stretching sheet. International Communications in Heat and Mass Transfer 35: 347-356.

[7] Malvandi A, Hedayati F, Domairry G. (2013). Stagnation point flow of a nanofluid toward an exponentially stretching sheet with non-uniform heat generation/absorption. Journal of Thermodynamics 2013.

[8] Rohni M, Ahmad S, Pop I. (2014). Flow and heat transfer at a stagnation-point over an exponentially shrinking vertical sheet with suction. International Journal of Thermal Sciences 75: 164-170.

[9] Hussain S, Ahmad F., (2015). On the study of viscous fluid due to exponentially shrinking sheet in the presence of thermal radiation. Thermal Science 19(Suppl.1): 191-196.

[10] Ur-Rehman S, Nadeem S, Lee C. (2016). Series solution of magneto-hydrodynamic boundary layer flow over bi-directional exponentially stretching surfaces. Journal of the Brazilian Society of Mechanical Sciences and Engineering 38(2): 443-453.

[11] Emama TG, Elmaboud TA. (2017). Three-dimensional magneto-hydrodynamic flow over an exponentially stretching surface. Int. J. of Heat and Technology 35(4): 987-996.

[12] Kumar PBS, Gireesha BJ, Gorla RSR, Mahanthesh B. (2017). Magnetohydrodynamic flow of Williamson nanofluid due to an exponentially stretching surface in the presence of thermal radiation and chemical reaction. J. of Nanofluids 6(2): 264-272.

[13] Aleng NL, Bachok N, Arifin NM. (2018). Dual solutions of exponentially stretched/shrinked flows of nanofluids. Journal of Nanofluids 7(1): 195-202.

[14] Srinivasacharya D, Jagadeeshwar P. (2018). Flow over an exponentially stretching porous sheet with cross-diffusion effects and convective thermal conditions. Int. J. of Engineering Transactions A: Basics 31(1): 120-127.

[15] Hayat T, Nadeem S. (2018). Flow of 3D Eyring-Powell fluid by utilizing Cattaneo-Christov heat flux model and chemical process over an exponentially stretching surface. Results in Physics 8: 397-403.

[16] Lai FC, Kulacki FA. (1991). The effect of variable viscosity on convective heat and mass transfer along a vertical surface in saturated porous media. Int. J. of

Heat and Mass Transfer 33: 1028-1031.
[17] Chaim TC. (1996). Heat transfer with variable thermal conductivity in a stagnation-point flow towards a stretching sheet. Int. Commun. Heat Mass Transfer 23(2): 239-248.
[18] Chiam TC. (1998). Heat transfer in a fluid with variable thermal conductivity over a linearly stretching sheet. Acta Mechanica 129: 63-72.
[19] Khan Y, Wua Q, Faraz N, Yildirim A. (2011). The effects of variable viscosity and thermal conductivity on a thin film flow over a shrinking/stretching sheet. Computers and Mathematics with Applications 61: 3391-3399.
[20] Rahman GMA. (2013). Effects of variable viscosity and thermal conductivity on unsteady MHD flow of non-Newtonian fluid over a stretching porous sheet. Thermal Science 17(4): 1035-1047.
[21] Siddheshwar PG, Sekhar GN, Chethan AS. (2014). Flow and heat transfer in a Newtonian liquid with temperature dependent properties over an exponential stretching sheet. Journal of Applied Fluid Mechanics 7(2): 367-374.
[22] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. (2015). Soret and Dufour effects in three-dimensional flow over an exponentially stretching surface with porous medium, chemical reaction and heat source/sink. International Journal of Numerical Methods for Heat \& Fluid Flow 25(4): 762-781.
[23] Megahed AM. (2015). Flow and heat transfer of Powell-Eyring fluid due to an exponential stretching sheet with heat flux and variable thermal conductivity. Zeitschrift für Naturforschung A 70(3): 163-169.
[24] Hazarika GC, Phukan B. (2017). Effects of variable viscosity and thermal conductivity on steady magnetohydrodynamic flow of a micropolar fluid through a specially characterized horizontal channel. Modelling Measurement and Control B 86(1): 1-13.
[25] Srinivasacharya D, Jagadeeshwar P. (2018). Effect of variable viscosity, thermal conductivity and Hall currents on the flow over an exponentially stretching sheet with heat generation/absorption. International Journal of Energy for a Clean Environment 19(1): 1-17. 10.1615/InterJEnerCleanEnv.2018021746
[26] Motsa SS, Shateyi S. (2011). Successive Linearisation solution of free convection non-Darcy flow with heat and mass transfer. Advanced Topics in Mass Transfer 19: 425-438.
[27] Awad FG, Sibanda P, Motsa SS, Makinde OD. (2011). Convection from an inverted cone in a porous medium with cross-diffusion effects. Computers and Mathematics with Applications 619(5): 1431-1441.
[28] Canuto, Hussaini MY, Quarteroni A, Zang TA. (2006). Spectral Methods: Fundamentals in Single Domains. Springer-Verlag Berlin Heidelberg.