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Comparative study of chemically reacting Blasius and Sakiadis unsteady MHD radiated flow with variable conductivity

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Abstract: This study aims to investigate the effects of unsteady MHD chemically reacting radiated flow with variable conductivity about a flat plate in a uniform stream of fluid (Blasius flow), and about a sheet in a quiescent ambient fluid(Sakiadis flow) both under a convective surface boundary condition. Numerical solutions are offered graphically and tabular form with the aid of shooting approximation. Results for Blasius and Sakiadis flow cases are exhibited through plots for the parameters of concern. It is observed that the heat and mass transfer rate is high in Blasius flow when compared with Sakiadis flow.

1 Introduction:

The study of the magnetohydrodynamic flow of an electrically conducting fluid over a heated surface has attracted several investigators in view of its significant real-life applications in numerous engineering areas, like petroleum industries, plasma studies, cooling of nuclear reactors, magnetohydrodynamic power generators, the boundary layer resistor in aerodynamics and crystal growth. The problem of steady free, forced and mixed convection on the magnetohydrodynamic flow with a combination of various boundary flow characteristics and various geometries, such as horizontal, vertical and inclined surfaces, has been analyzed by several investigators [1-5], due to its significant practical and theoretical interest.

Scientists and researchers are still attracted in discovering the performance and characteristics over sheet or plate. It has various applications in the process metal spinning,aerospace, science and engineering etc. The effective work of flow over sheet and plate is given by the authors Blasius [6] and Sakiadis [7] in 19th century. Later on Anderson at al.[8] investigated the Sakiadis flow with variable fluid properties revisited.Ahmad et al. [9] deliberated Blasius and Sakiadis flow cases in nano fluids due to fluid flow and heat transfer characteristics. A new algorithm for solving the classical blasius equations has been investigated by Wang [10]. Kuo [11] discussed semi-infinite plot plate with thermal boundary layer problems due to differential transformation method. An explicit totally analytic approximation solution for a uniform stream of fluid flow problems has been discussed by Lio [12]. Later Cortell[13] studied numerical investigation of a uniform stream of fluid(the classical Blasius flat plate problem).Later a convective condition of Blasius equations by using the method of a simple perturbation approach has been investigated by He [14].

Sekhar et al. [15] discussed MHD Maxwell fluid Blasius and Sakiadis flows of exponentially decaying heat source/sink. Radiation effects of Blasius and Sakiadis flows of nanofluid have been demonstrated by Uddin et al. [16]. Hady et al. [17] presented Blasius and Sakiadis slip flow in a thermal radiation convective surface boundary condition in the presence of nanofluids with porous medium. Later on, Anuar et al. [18] discussed nanofluid properties of Buongiorno model and thermo-physical properties with Blasius and Sakiadis flow problem of nano-liquids. Mustafa et al. [19] investigated magnetic field and convective boundary conditions in the presence of Sakiadis slip flow with Maxwell fluid. An analysis of Blasius and Sakiadis slip flow of MHD Jeffrey fluid in the presence of non-uniform heat source/sink has been deliberated by Prasad et al. [20]. Cattaneo-Chrisov heat flux model with heat transfer analysis slip effects of Blasius and Sakiadis flow of MHD radiative Maxwell fluid have been analysed by Vinod et al. [21]. Sekhar et al. [22] investigated mixed convection Couette flow of a nanofluid through a vertical channel. Nadeem et al. [23] studied a numerical investigation for steady flow of a nanofluid past a stretching sheet due to Brownian motion.Several researches utilized convective conditions as a passive technique [24-30].

Motivated by the above investigations, the present analysisis focused on the study of unsteady MHD heat and mass transfer flow the effects of unsteady MHD chemically reacting radiated flow with variable conductivity about a flat plate in a uniform stream of fluid (Blasius flow), and about a sheet in a quiescent ambient fluid (Sakiadis flow) both under a convective surface boundary condition. Numerical solutions are offered graphically and tabular form with the aid of shooting approximation. Results for Blasius and Sakiadis flow cases are exhibited through plots for the parameters of concern. It is observed that the heat and mass transfer rate is high in Blasius flow when compared with Sakiadis flow. The numerical results of skin friction, Nusselt number, and Sherwood number are presented in tabular form whereas the graphical results are presented and discussed for various physical parameters influencing the fluid flows and heat and mass transfer characteristics.Exact solutions obtained in this paper are useful for explainingthe flow physics in detail.

2 Mathematical formulation

Consider the unsteady laminar two-dimensional boundary layer flow of a viscous incompressible fluid past a semi-infinite porous stretching sheet coinciding with the plane $y = 0$. The Cartesian coordinate system has its origin located at the leading edge of the sheet with the positive x-axis extending along the sheet in the upwards direction, while the y-axis is measured normal to the surface of the sheet and is positive in the direction of the sheet to the fluid. We assume that for time $t < 0$ the fluid and heat flows are steady. The unsteady fluid and heat flows start at $t = 0$, the sheet is being stretched with the velocity $U_w(x,t)$ along the x-axis, keeping the origin fixed. The temperature of the sheet $T_w(x,t)$ is assumed to be a linear function of x. The thermophysical properties of the sheet and the ambient fluid are assumed to be constant except density variations and the thermal conductivity which are assumed to vary linearly with temperature. Under these assumptions, the governing equations for continuity, momentum, thermal and diffusion equations Vajravelu et al. [31] given as

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

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \vartheta\frac{\partial^2 u}{\partial y^2} \pm g\beta_T(T - T_\infty) \pm g\beta_C(C - C_\infty) - \frac{\sigma B_0^2}{\rho}u - \frac{\vartheta}{K_0}u \tag{2}$$

$$\rho C_p\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \frac{\partial}{\partial y}\left(K(T)\frac{\partial T}{\partial y}\right) - Q(T - T_\infty) - \frac{\partial q_r}{\partial y} \tag{3}$$

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} - K_0(C - C_\infty) \tag{4}$$

Subject to the boundary conditions

i)   Blasius problem
$$\left.\begin{array}{l} v=0, u=0 \ \ at \ \ y=0 \\ u=U \ \ as \ \ y\to\infty \end{array}\right\}$$

ii)   Sakiadis problem
$$\left.\begin{array}{l} v=0, u=U \ \ at \ \ y=0 \\ u=0 \ \ as \ \ y\to\infty \end{array}\right\} \tag{5}$$

$$T=T_w, C=C_w \ at \ y=0, \ \ T=T_\infty, C=C_\infty \ as \ y\to\infty$$

Where u and v are the velocity components in the x and y directions, respectively, T is the fluid temperature inside the boundary layer and υ is the kinematic viscosity. Ishak et al [32] assume that the stretching velocity $U_w(x,t)$ is of the form

$$U_w(x,t) = \frac{ax}{1-ct}$$

Where a and c constants (with $a\geq 0$ and $c\geq 0$ where $ct<1$), and both have dimension t^{-1}, we have a as the initial stretching rate $\frac{a}{1-ct}$ and it is increasing with time. In the context of polymer extrusion, the material properties, in particular, the elasticity of the extruded sheet may vary with time even though the sheet is being stretched by a constant force. With unsteady stretching, however, a^{-1} becomes the representative time scale of the resulting unsteady boundary layer problem. We assume the surface temperature $T_w(x,t)$ and concentration $C_w(x,t)$ of the stretching sheet to vary with distance x and inverse square law for its decrease with time in the following form:

$$T_w(x,t) = T_\infty + \frac{bx}{(1-ct)^2} \ \ C_w(x,t) = C_\infty + \phi\frac{bx}{(1-ct)^2}$$

Here b is the constant and has dimension temperature or length, with $b>0$ and $b<0$ corresponding to the assisting opposing flow, respectively, and $b=0$ is for the forced convection limit (absence of buoyancy force). These particular forms of $u_w(x,t), T_w(x,t)$ and $C_w(x,t)$ have been chosen in order to obtain a new similarity transformation, which transforms the governing equations (1) to (4) into as a set of coupled ordinary differentiable equations, thereby facilitating the exploration of the effects of the controlling parameters.

We introduce now the following dimensionless functions f, θ and ϕ with the similarity variable ς (see Vajravelu et al. [34])

$$\zeta = \left(\frac{a}{\vartheta(1-ct)}\right)^{1/2} y, \psi = \left(\frac{\vartheta a}{(1-ct)}\right)^{1/2} xf(\zeta), \theta(\zeta) = \frac{(T-T_\infty)}{(T_w - T_\infty)}, \phi(\zeta) = \frac{(C-C_\infty)}{(C_w - C_\infty)},$$

$$A = \frac{c}{a}, \Pr = \frac{\mu c_p}{k}, f_w = \frac{v_0}{\sqrt{\upsilon a}}, \lambda = \frac{g\beta b}{a^2}, Gr_x = \frac{g\beta(T_w - T_\infty)x^3}{\upsilon^2}, Nr = \frac{16T_\infty^3 \sigma_0}{3k^* K_\infty}, M = \frac{\sigma B^2}{\rho U_\infty}, Kr = \frac{kr\upsilon^2}{D_m U_\infty^2}$$

$$(6)$$

Where $\psi(x.y,t)$ a stream function is defined as $(u,v) = \left(\frac{\partial \psi}{\partial y}, -\frac{\partial \psi}{\partial x}\right)$ which identically satisfies the continuity equation (1).

Substituting Eq. (6) in Eqs. (2)- (4) We obtain

$$f''' + ff'' - f'^2 - A\left(f' + \frac{1}{2}\zeta f''\right) \pm \lambda_T \theta \pm \lambda_C \phi - (M+K)f' = 0 \tag{7}$$

$$\frac{1}{\Pr}\left(\theta'' + \varepsilon\theta'^2 + \varepsilon\theta\theta''\right) - Q_H \theta + \frac{Nr}{\Pr}\theta'' + f\theta' - \theta f' - \frac{A}{2}\zeta\theta' - 2A\theta = 0 \tag{8}$$

$$\frac{1}{Sc}\phi'' + (f\phi' - \phi f') - \frac{A}{2}\zeta\phi' - 2A\phi - KrA\phi = 0 \tag{9}$$

Boundary condition's are

  i)   Blasius problem
        $f(0) = 0, \ f'(0) = 0, \ \theta(0) = 1, \ \phi(0) = 1, \ f'(\infty) = 1, \ \theta(\infty) = 0, \ \phi(\infty) = 0$
  ii)   Sakiadis problem
        $f(0) = 0, \ f'(0) = 1, \ \theta(0) = 1, \ \phi(0) = 1, \ f'(\infty) = 0, \ \theta(\infty) = 0, \ \phi(\infty) = 0$
        (10)

Where primes denote differentiation with respect to ζ. $v_w(t) = \frac{v_0}{\sqrt{1-ct}}$ is the suction or injection velocity and q_r is the radiative heat flux. The second and third terms in Eq.(2)are due to the buoyancy force. The "+" and "-" signs refer to the buoyancy assisting and buoyancy opposing flow situations, respectively.

In the present study, the thermal conductivity is assumed to vary linearly with temperature as

$$K(T) = K_\infty\left(1 + \frac{\varepsilon}{\Delta T}(T - T_\infty)\right)$$

Here, $\Delta T = (T_w - T_\infty)$

The radiative flux can be expressed as

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$$

We assume that the temperature difference within the flow s such that the term T^4 can be expressed as in a Taylor series about T_∞ and neglecting higher order terms, we obtain

$$T^4 \approx 4T_\infty^3 T - T_\infty^4$$

The physical quantities of interest are the local heat flux and local mass flux, which is defined as

$$C_f = \frac{\tau_w}{\rho U_w^2 / 2}, Nu_x = \frac{xq_w}{K_\infty (T_w - T_\infty)},$$

Where the skin friction τ_w and the heat transfer q_w from the sheet given by

$$\tau_w = \mu \left(\frac{\partial u}{\partial y} \right)_{y=0}, q_w = -K_\infty \left(\frac{\partial T}{\partial y} \right)_{y=0}$$

3 Results and discussion:

In order to achieve a strong approval of the physical model, numerical solutions for the dimensionless velocity, temperature and concentration as well as the local Nusselt, Sherwood numbers and friction factor coefficients are presented with the assistance of graphical and tabular illustrations for several values of pertinent parameters for both the cases of Blasius and Sakiadis. For numerical computations we fix the non-dimensional quantities as $Q_H = 0.2, K = 0.5, \text{Pr} = 0.70, \lambda_T = 0.5, \lambda_C = 0.5, \varepsilon = 0.2, A = 0.2, M = 0.5, Kr = 0.2, Nr = 0.5, Sc = 1, \varsigma = 0.5$ .These values are preserved as common in the whole analysis excluding the different values that are presented in the figures and tables. In this study the graphs in solid and dashed line indicates the Blasius and Sakiadis flow cases respectively.

Figs 1-10 illustrate the dissimilarities of velocity, temperature and concentration distributions for various values of $Q_H, Kr, M, K, \varepsilon, Nr$ respectively. In Fig.1 plot to examine the effect ofheat source parameter Q_H on temperature field for Blasius and Sakiadis flow cases. It is clear that an increasing Q_H tends to decreases for thickness of thermal boundary layer.

The effect ofchemical reaction parameter Kr on the velocity and concentration are displayed in Figs. 2&3. It is (observed that) worth to mention that the velocity and concentration profiles are diminishes with increasing Kr . Since lessen the momentum and mass boundary layer thickness.

Figs. 4-6 show the effect of the Magnetic field parameter M on velocity, temperature and concentration fields for both the Blasius and Sakiadis flow cases. It is observed that increasing values of M lessen the velocity profiles and intensifies the temperature and concentration distributions. If there is a smaller amount dominance of viscous forces on Lorentz force, that leads to a decrease in the velocity and to decelerates in the temperature and concentration fields.

Figs. 7 and 8 display the effect ofporosity parameter K on velocity and concentration distributions. It will watch that an increasing values of K diminishes for momentum boundary layer thickness and induces for mass boundary layer both the cases of blasius and Sakiadis flow respectively. The influence of the small parameter ε and thermal radiation parameter Nr on the temperature field are shown in Figs. 9 and 10. It will see that both the cases of thermal boundary layer thickness intensifies for ε and Nr respectively.
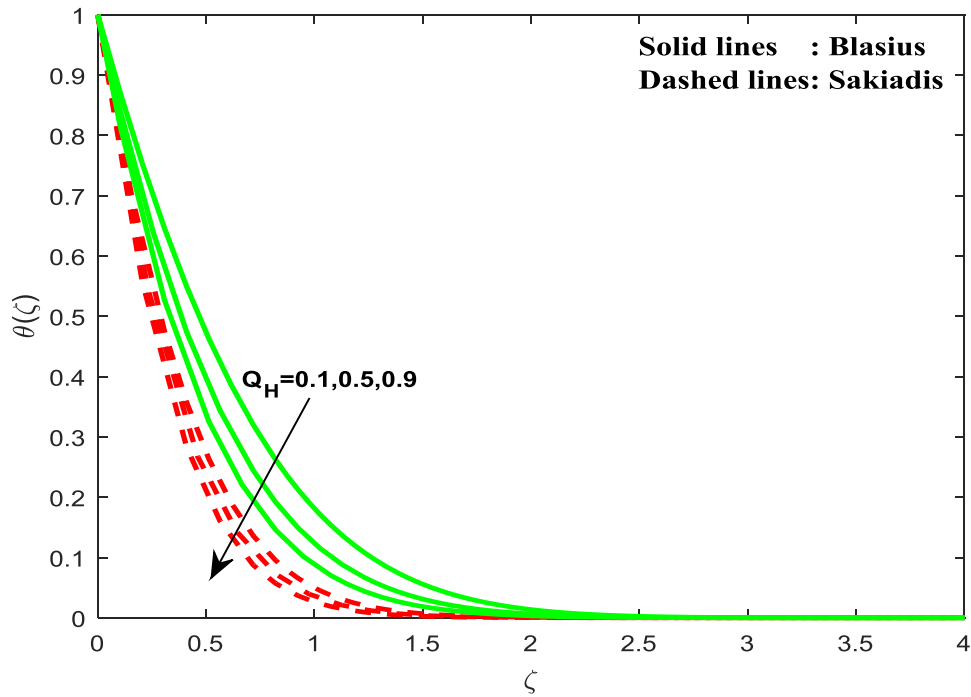
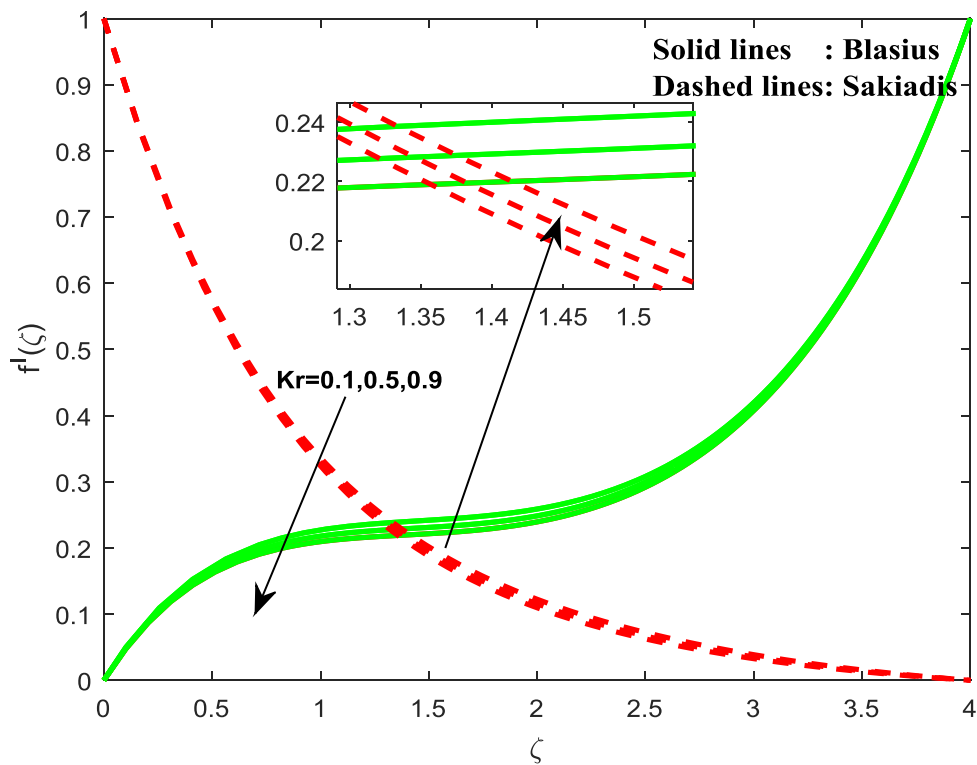Fig.1. Temperature profile for various values of Q_H

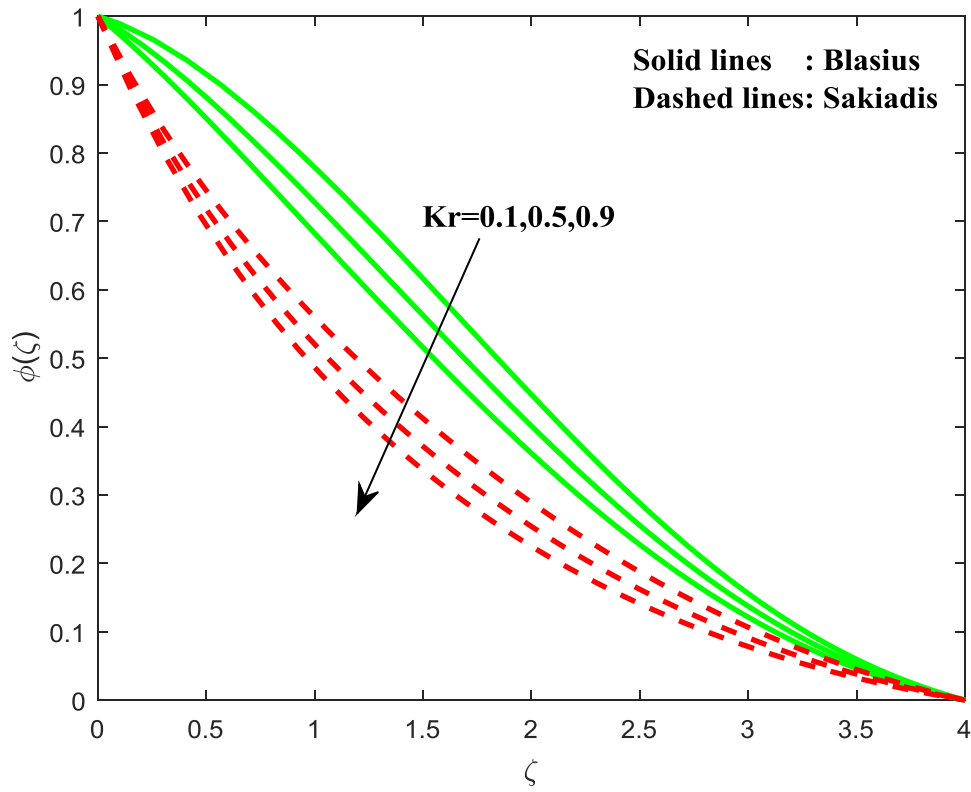Fig.2. Velocity profile for various values of Kr

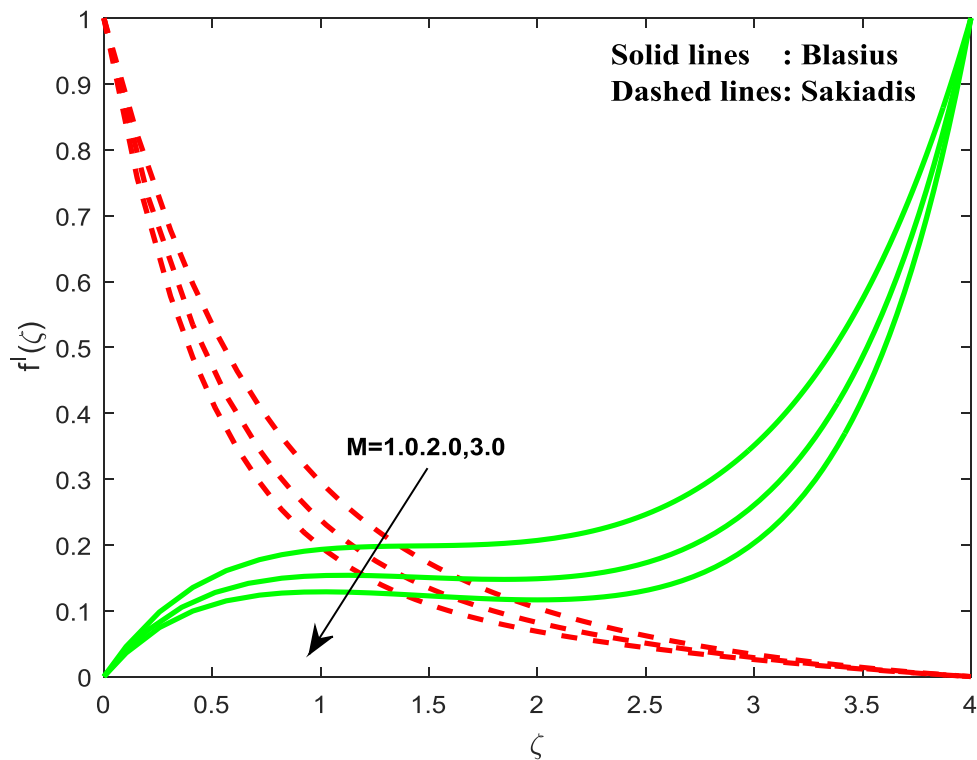Fig.3. Concentration profile for various values of *Kr*

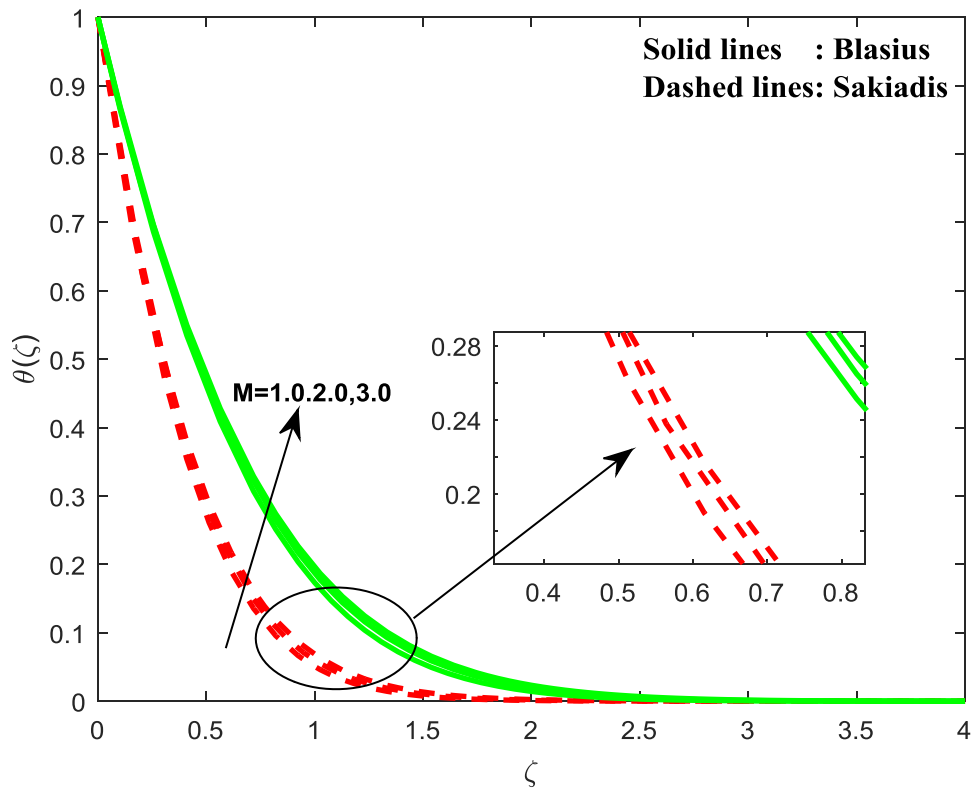Fig.4. Velocity profile for various values of *M*

Fig.5. Temperature profile for various values of M

Fig.6. Concentration profile for various values of M

Solid lines   : Blasius
Dashed lines: Sakiadis

K=1.0,2.0,3.0

Fig.7. Velocity profile for various values of K

Solid lines   : Blasius
Dashed lines: Sakiadis
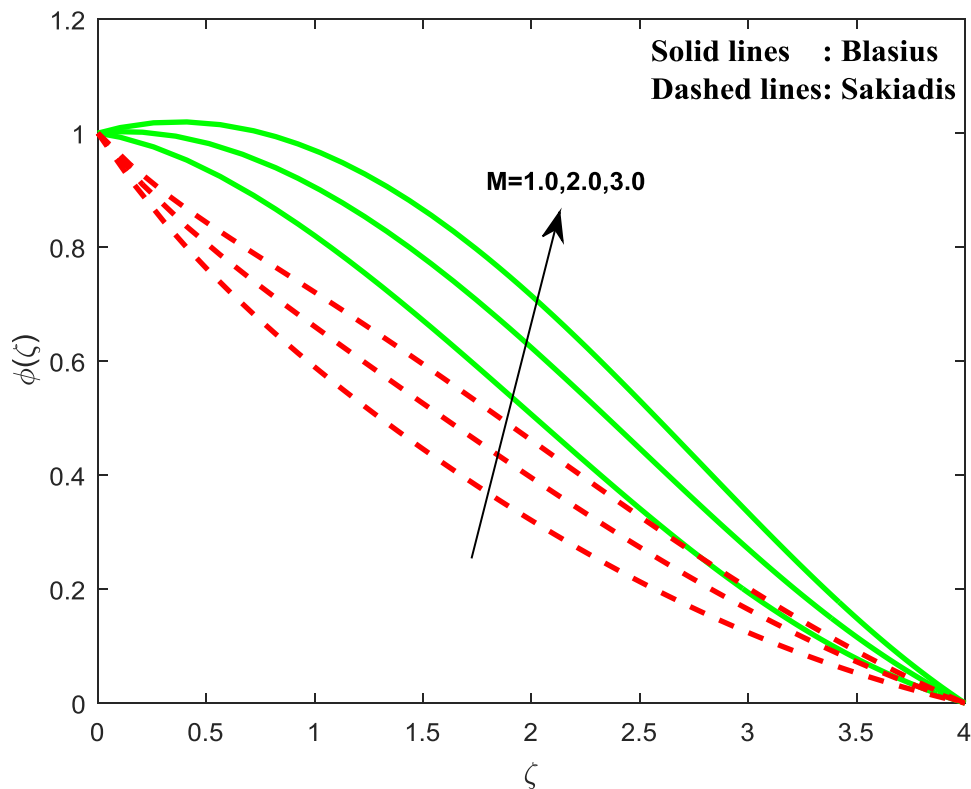
K=1.0,2.0,3.0
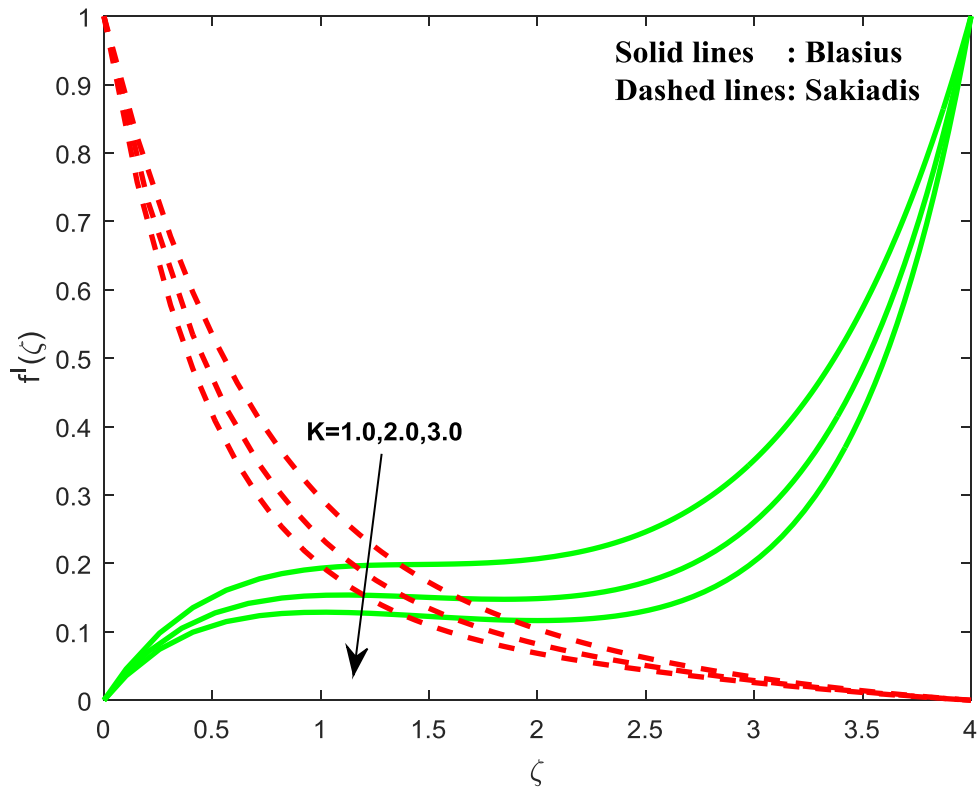
Fig.8. Concentration profile for various values of K

Fig.9. Temperature profile for various values of ε

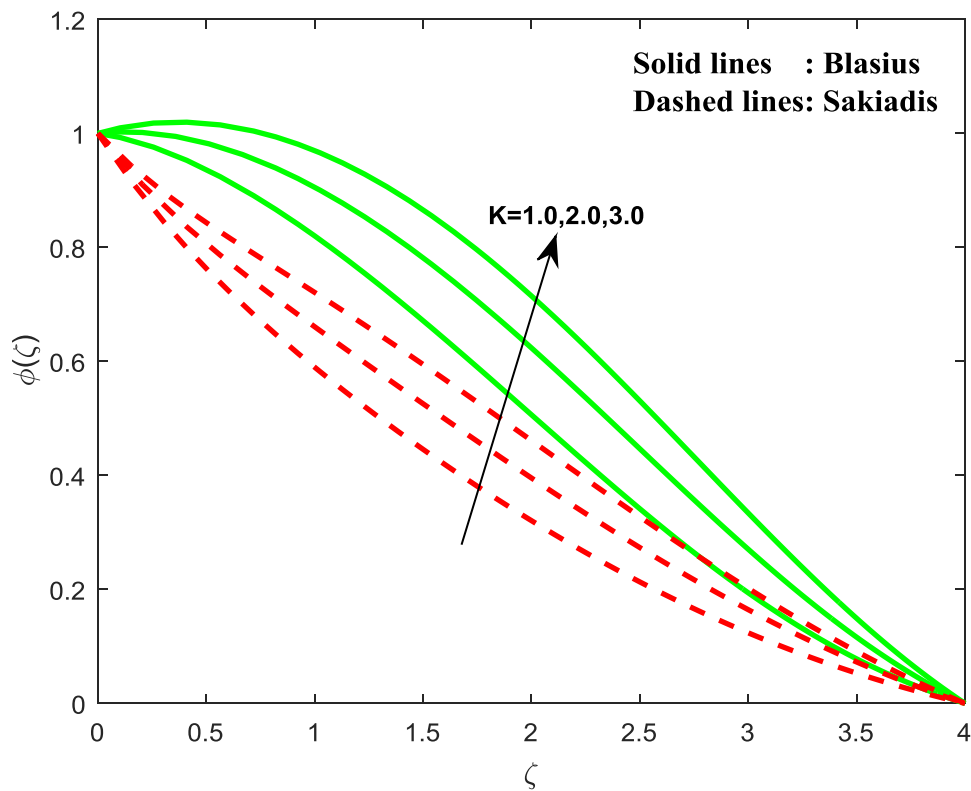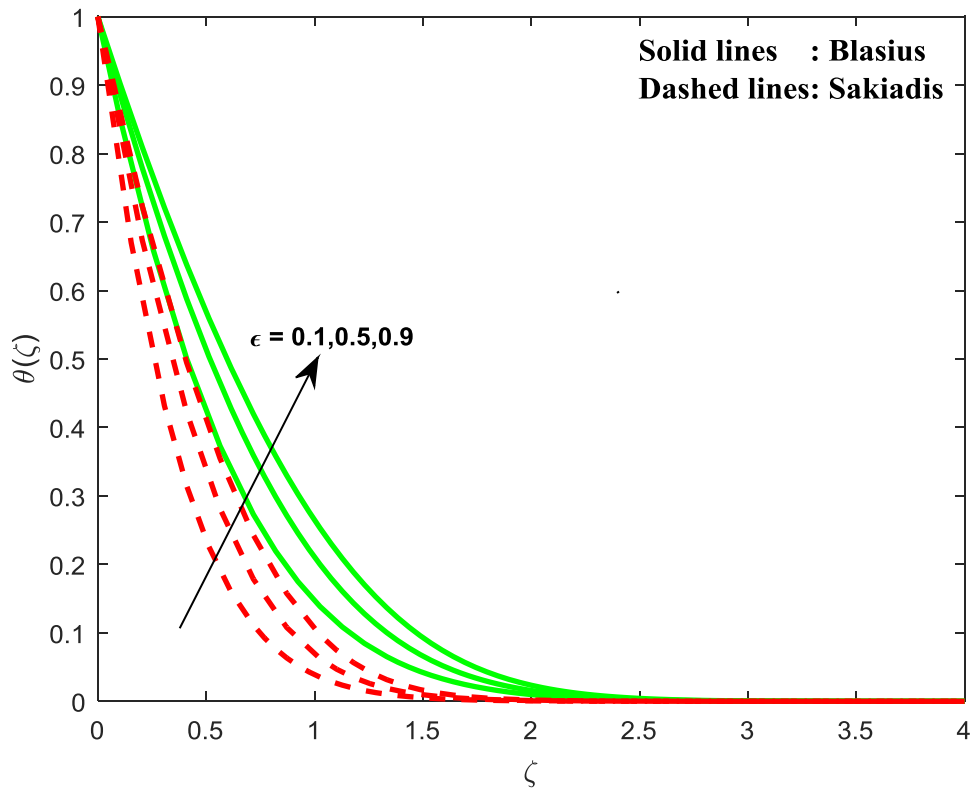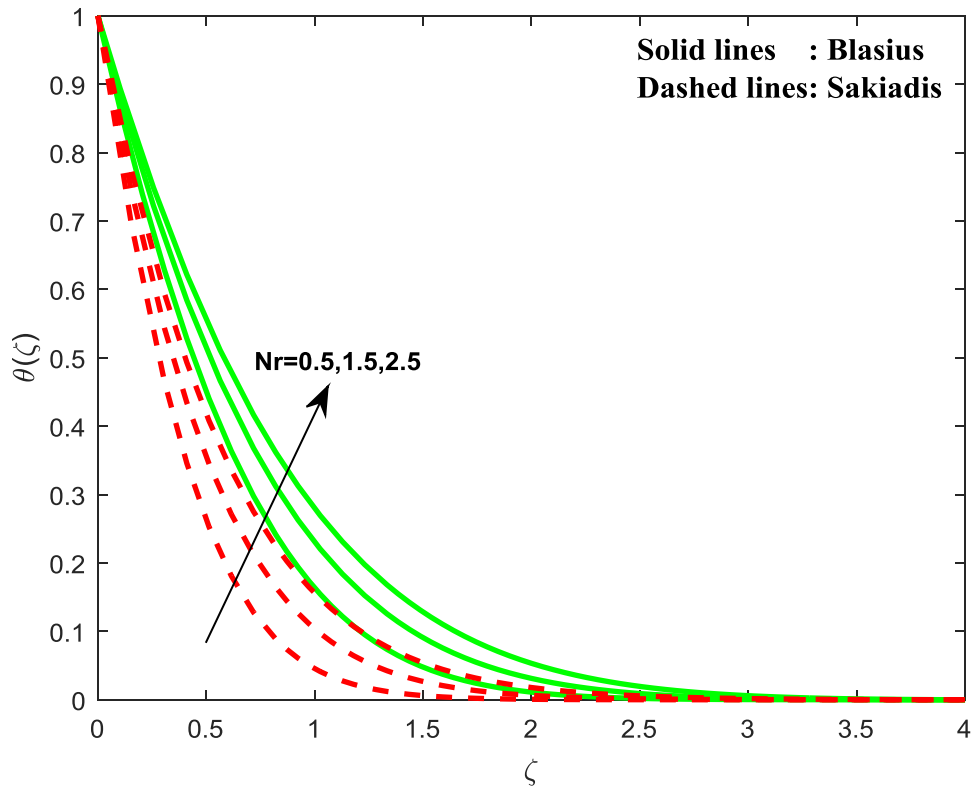Fig.10. Temperature profile for various values of Nr

Table-1: Values of skin friction, Nusselt and Sherwood number for variousvalues $Q_H, Kr, M, K, \varepsilon, Nr$ for Blasius flow.

Q_H	Kr	M	K	ε	Nr	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1						0.578857	4.258094	0.148515
0.5						0.563718	5.253961	0.136378
0.9						0.552111	6.112425	0.127584
	0.1					0.537540	20.873748	0.089934
	0.5					0.525626	20.799934	0.176429
	0.9					0.514999	20.733666	0.176429
		1.0				-1.270266	32.924139	0.585030
		2.0				-1.569767	32.255475	0.490082
		3.0				-1.831013	31.690288	0.410044
			1.0			0.492635	20.597214	0.051654
			2.0			0.435509	20.244390	-0.042228
			3.0			0.396353	20.004623	-0.112406
				0.1		0.528495	22.931926	0.109187
				0.5		0.547838	17.180829	0.120184
				0.9		0.560272	14.582052	0.128551
					0.5	0.534430	20.854538	0.112311
					1.5	0.549249	6.799505	0.123555
					2.5	0.559790	4.084755	0.132251

Table-2: Values of skin friction, Nusselt and Sherwood number for variousvalues $Q_H, Kr, M, K, \varepsilon, Nr$ for Sakiadis flow

Q_H	Kr	M	K	ε	Nr	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1						-1.050901	6.350963	0.665137
0.5						-1.060460	7.175090	0.659406
0.9						-1.067927	7.902276	0.655279
	0.1					-1.098003	33.320660	0.620963
	0.5					-1.106522	33.288395	0.692440
	0.9					-1.113909	33.260396	0.757103
		1.0				0.492635	20.597214	0.051654
		2.0				0.435509	20.244390	-0.042228
		3.0				0.396353	20.004623	-0.112406
			1.0			-1.270266	32.924139	0.585030
			2.0			-1.569767	32.255475	0.490082
			3.0			-1.831013	31.690288	0.410044
				0.1		-1.105659	37.076239	0.638102
				0.5		-1.087361	26.659897	0.643527
				0.9		-1.074535	21.973083	0.648258
					0.5	-1.100252	33.312144	0.639554
					1.5	-1.083432	10.480840	0.646777
					2.5	-1.071054	6.136145	0.653174

Tables 1 and 2 exhibits the validation of the pertinent parameters on skin friction coefficient, reduced Nusselt number and Sherwood numbers for both cases of Blasius and Sakiadis flow characteristics respectively. This will say that for skin friction coefficient Q_H, Kr, M, K diminishes and reverse phenomenon for the parameters ε, Nr for both the Blasius and Sakiadis slip flows respectively. For reduced Nusselt number Q_H intensifies and the remaining parameters are opposite behaviour for Blasius and Sakiadis slip cases. It is also observed that for Sherwood number Q_H, M, K diminishes and Kr, ε, Nr intensifies for flow dimensions.

4 Conclusions:

1. The increasing values of K diminishes for momentum boundary layer thickness and induces for mass boundary layer both the cases of blasius and Sakiadis flow.
2. The skin friction coefficient Q_H decelerates for Blasius and Sakiadis slip cases.
3. The friction factor rate Kr, M, K suppressfor Blasius and Sakiadis slip cases.
4. The thermal boundary layer thickness intensifies for ε and Nr for both cases.

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