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Flow and mass transfer effects on viscous fluid in a porous channel with moving/stationary walls in presence of chemical reaction ☆

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ABSTRACT

An analysis is performed to study the effects of mass transfer and chemical reaction on laminar flow in a porous channel with moving or stationary walls. The governing equations are reduced to non-linear ordinary differential equations based on the physics of the flow. An analytical approach, namely, the homotopy analysis method (HAM) is applied in order to obtain the solutions of the ordinary differential equations. The convergence of the obtained series solutions is analyzed. The effects of various parameters on flow variables have been discussed. Comparisons of the HAM solutions with the numerical solutions using shooting method coupled with Runge–Kutta scheme are in excellent agreement.

1. Introduction

The study of laminar flow in porous pipe or channel has received considerable attention in the past few years due to its applications in technological and biological sciences. The earliest work of steady flow across permeable and stationary walls can be traced back to Berman [1]. Debruge and Han [2] have described a method of cooling turbine blades internally by continuous injection through an interior baffle. In recent years, a lot of attention has been drawn to study the flow characteristics in channels filled with porous media, which has important applications in many fields of engineering such as filtration and purification processes, geological studies and petroleum industries ([3–7] and several references therein). Seyf and Rassoulinejad-Mousavi [7] obtained analytical solutions for fluid flow in porous media imbedded in side a channel with moving/stationary walls by using the homotopy perturbation method. Jankowski and Majdalani [8] have studied laminar flow in a porous channel with large wall suction and a weakly oscillatory pressure.

The study of heat and mass transfer with a chemical reaction is of great practical importance in many branches of science and engineering. Possible applications of this type of flow can be found in many industry and engineering applications such as nuclear reactor safety, combustion systems, solar collectors, metallurgy, and chemical engineering ([9–13] and several references therein). Hayat et al. [14] have studied the effects of mass transfer on the stagnation point flow of an upper-convected Maxwell (UCM) fluid using HAM. Reddy et al. [15] have analyzed the influence of heat transfer and chemical reaction on asymmetric laminar flow between two slowly expanding or contracting walls using double perturbation expressions in the permeation Reynolds number and the wall expansion ratio.

It is noted through the survey of literature that no attempt has been made so far regarding the study of mass transfer effects with chemical reaction on viscous flow in a porous channel with moving or stationary walls with chemical reaction. Keeping in view the wide range of applications in many fields of engineering and motivated by previous works (Seyf and Rassoulinejad-Mousavi [7], Hayat and Abbas [10]), an attempt has been made to study the effects of mass transfer and chemical reaction on viscous flow in a porous channel with moving or stationary walls. The governing equations are transformed into ordinary differential equations using a similarity transformation based on the physics of the flow. The resulting system is then solved using a powerful technique namely the homotopy analysis method (HAM) [16], which has been applied successfully to many interesting problems [17–19].

2. Formulation of the problem

Consider the steady, laminar, isothermal and incompressible flow in a rectangular domain bounded by two permeable surfaces. The physical model and geometric configuration of the channel with various boundary conditions at the walls is shown in Fig. 1.A. The x-axis is taken in direction of flow and the y-axis is perpendicular to the horizontal walls of the channel. Injection and suction at the walls are assumed to be constant and uniform. Let v_t and v_b be normal velocities at the walls where the subscript t stands for top and b stands for bottom wall respectively. In general, v_t and v_b are different and thus various combinations of these parameters give rise to different types of flows. In particular, $v_t < 0$ and $v_b > 0$ corresponds to pure injection, $v_t > 0$ and $v_b < 0$ represent pure suction, etc. It is assumed that the axial velocities of the walls are linear. The channel is filled with porous medium

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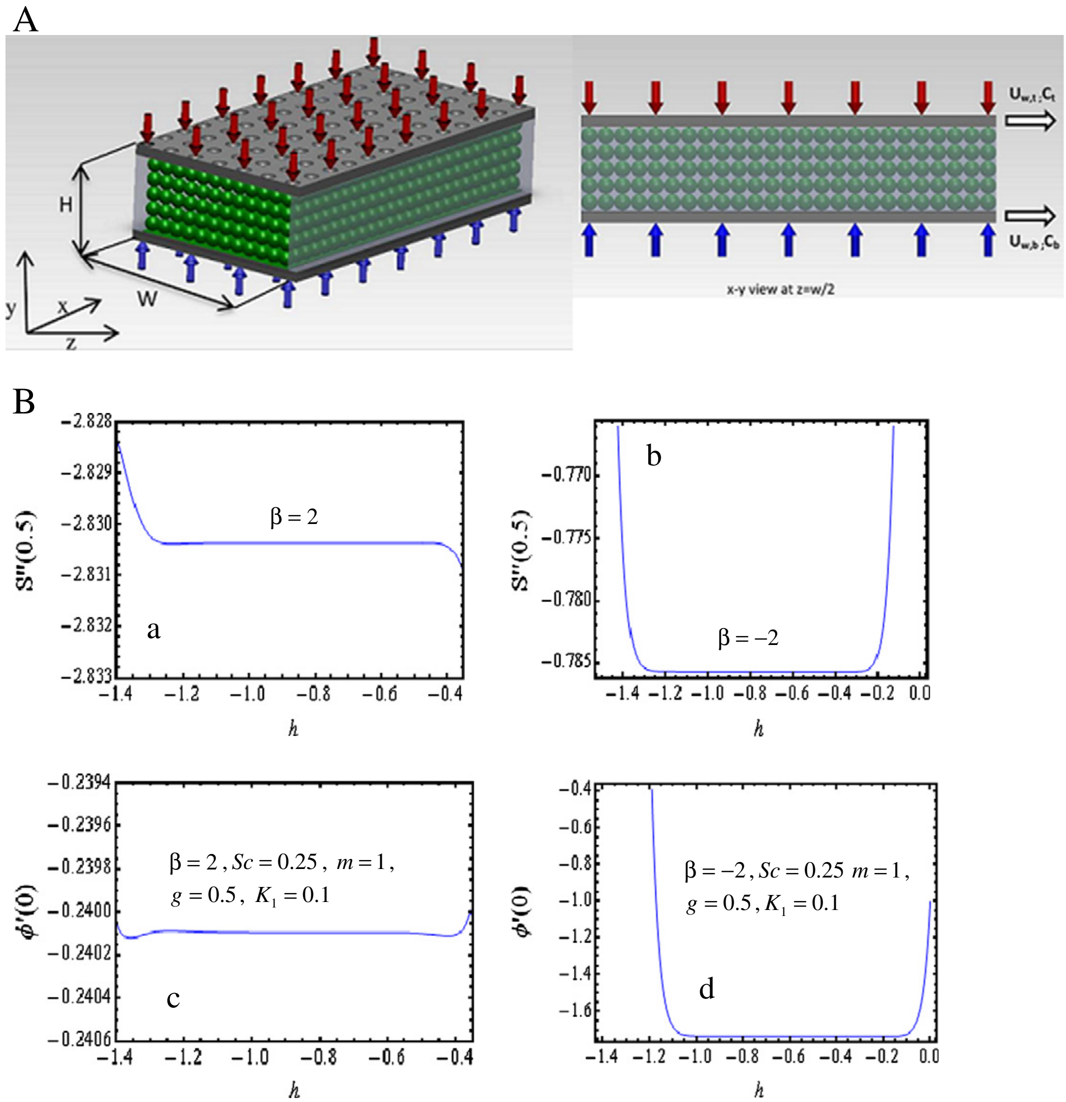

Fig. 1. A. Schematic of the flow geometry with various boundary conditions. B. h curves on the 20th order approximations for the functions S,φ. $\lambda = 1$, $\gamma = 1$, $Da = 0.01$, $\alpha = 1$, $\varepsilon = 0.7$, $\mathrm{Re} = 2$.

with height H, axial length L, and width W. We assume that the width of the channel is much greater than the height of the channel, i.e., $W \gg H$, therefore, the present study is a two-dimensional model. Under these assumptions, Seyf and Rassoulinejad-Mousavi [7] obtained the following nonlinear ordinary differential equation which is the transformed version of the physical problem

$$S^{IV} + \mathrm{Re}SS''' - \mathrm{Re}S'S'' - \frac{\varepsilon}{Da}S'' = 0, \quad (1)$$

along with the corresponding boundary conditions

$$S'(0) = \lambda; \qquad S'(1) = \gamma; \qquad S(0) = -\alpha; \qquad S(1) = -\beta. \quad (2)$$

where $\mathrm{Re} = \rho v_b H/\mu$ is the Reynolds number and $Da = k/H^2$ is the Darcy number of the porous media.

$$\alpha = \begin{cases} 1, & \text{for injection} \\ -1, & \text{for suction} \end{cases}; \quad \beta = v_t/v_b; \quad \lambda = u_b/v_b; \quad \gamma = u_t/v_b. \quad (3)$$

The mass-species conservation equation, assuming that there exists a homogeneous first order chemical reaction between the fluid and species concentration, is

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - k_1 C \quad (4)$$

with the corresponding boundary conditions

$$C = C_b \text{ at } y = 0 \text{ and } C = C_t \text{ at } y = H$$

where u, v are the dimensional components of velocity along the x and y directions respectively, D is the coefficient of mass diffusivity, k_1 is the first order chemical reaction rate ($k_1 > 0$ for destructive reaction, $k_1 = 0$ represents no reaction and $k_1 < 0$ for generative reaction), C_b is the concentration at the bottom wall, C_t is the concentration at the top wall and C is the dimensional concentration of the fluid.

The concentration of the fluid in the channel can be expressed as

$$C = C_t + A\left(\frac{x}{H}\right)^m \phi(Y) \quad (5)$$