航空技術學院學報 第二十卷　　第 83-94 頁(民國 110 年)
Journal of Air Force Institute of Technology, Vol. 20, pp. 83-94, 2021

Uniform Blowing/Suction and Soret/Dufour Effects on Heat and Mass Transfer by Natural Convection about a Vertical Cone in Porous Media: UHF/UMF

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Abstract

The uniform blowing/suction and Soret/Dufour effects on heat and mass transfer by the natural convection about the vertical cone embedded in a saturated porous medium is numerically analyzed. The surface of the vertical cone is maintained at uniform heat flux and uniform mass flux (UHF/UMF). The transformed governing equations are solved by Keller box method. Numerical data for the dimensionless temperature profile, the dimensionless concentration profile, the local Nusselt number and the local Sherwood number are presented for the blowing/suction parameter ξ, the buoyancy ratio N, the Lewis number Le, the Soret parameter S, and the Dufour parameter D. In general, for the case of suction, both the local surface heat and mass transfer rates increases. This trend reversed for blowing of fluid. As the buoyancy ratio increases both the local Nusselt number and the local Sherwood number increase. The local Nusselt (Sherwood) number increases (decreases) with decreasing the Lewis number. As the Soret parameter increases, the local Nusselt number tends to increase and the local Sherwood number tends to decrease. Increasing the Dufour parameter tends to decrease the local Nusselt number and increase the local Sherwood number.

Keywords: uniform blowing/suction and Soret/Dufour effects, heat and mass transfer natural convection, vertical cone, saturated porous media, UHF/UMF

均勻噴/吸流與Soret/Dufour效應對於飽和多孔性介質內垂直圓錐體自然對流熱與質量傳遞之影響：均勻熱通量/均勻質通量

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摘　要

本文以一數值方法來分析：均勻噴/吸流與Soret/Dufour效應對於飽和多孔性介質內垂直圓錐體自然對流熱與質量傳遞之影響。垂直圓錐體的表面為均勻熱通量與均勻質通量。吾人以凱勒盒子法來解轉換過的控制方程式。數值計算結果主要顯示噴吸流參數ξ、Le參

數，浮力比N，Soret參數S，和Dufour參數D，對無因次溫度分佈、無因次濃度分佈、局部Nusselt數和局部Sherwood數之影響。一般而言，局部表面熱與質量傳遞率均因吸入流效應而增加。對噴出流效應則減少。浮力比愈大，則增加局部Nusselt數和局部Sherwood數。局部Nusselt數（Sherwood數）隨著Le參數的降低而增加（降低）。當Soret參數增加時，局部Nusselt數會增加；而局部Sherwood數卻降低。增加Dufour參數，導致降低局部Nusselt數與增加局部Sherwood數。

關鍵字： 均勻噴/吸流與Soret/Dufour效應，熱與質傳自然對流，垂直圓錐體，飽和多孔性介質，均勻熱通量/均勻質通量

1. Introduction

Coupled heat and mass transfer (or double-diffusion) driven by buoyancy, due to temperature and concentration variations in a saturated porous medium, has several important applications in geothermal and geophysical engineering, for example, the migration of moisture in fibrous insulation and the underground disposal of nuclear wastes. Recent books by Nield and Bejan [1] and Ingham and Pop [2-3] present a comprehensive account of the available information in the field.

In the coupled heat and mass transfer processes, it is known that the thermal energy flux resulting from concentration gradients is referred to as the Dufour (diffusion-thermal) effect. Similarly, the Soret (thermo-diffusion) effect is the contribution to the mass fluxes due to temperature gradients. The Dufour and Soret effects are considered as second order phenomena, on the basis that they are of smaller order of magnitude than the effects described by Fourier's and Fick's laws, but they may become significant in the areas of geosciences and chemical engineering.

There are a few studies about the Dufour and Soret effects in a pure Darcy porous medium. Postelnicu [4] has investigated the coupled heat and mass transfer by natural convection from a vertical flat plate embedded in an electrically-conducting fluid saturated porous medium using the Darcy-Boussinesq model in the presence of Dufour and Soret effects. Postelnicu [5] studied the influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Soret and Dufour effects on free convection heat and mass transfer in a doubly stratified Darcy porous medium was presented by Lakshmi Narayana [6]. Lakshmi Narayana and Murthy [7] analyzed the Soret and Dufour effects on free convection heat and mass transfer from a horizontal flat plate in a Darcy porous medium. Cheng [8] reported the Soret and Dufour effects on natural convection heat and mass transfer from a vertical cone in a porous medium with uniform wall temperature and concentration (UWT/UWC). Cheng [9] examined the Soret and Dufour effects on free convection boundary layer over a vertical cylinder in a saturated porous medium with uniform wall temperature and concentration (UWT/UWC). The Soret and Dufour effects on heat and mass transfer by natural convection from a vertical truncated cone in a fluid-saturated porous medium with variable wall temperature and concentration (VWT/VWC) was studied by Cheng [10]. Magyari and Postelnicu [11] presented the double-diffusive natural convection flows with thermosolutal symmetry in porous media in the presence of the Soret-Dufour effects with uniform wall heat flux and uniform wall mass flux (UHF/UMF). Cheng [12] examined the Soret and Dufour effects on natural convection boundary layer flow over a vertical cone in a porous medium with uniform wall heat and mass fluxes (UHF/UMF). Cheng [13] investigated the Soret and Dufour effects on natural convection heat and mass transfer near a vertical wavy cone in a porous medium with uniform wall temperature and concentration (UWT/UWC). Cheng [14] investigated the Soret and Dufour effects on double-diffusive free convection over a vertical truncated cone in porous media with variable wall heat and mass fluxes (VHF/VMF). **Tu** et al. [15] presented Taguchi method and numerical simulation for variable viscosity and non-linear Boussinesq effects on natural convection over a vertical truncated cone in porous media. Huang and Yih [16] analyzed nonlinear radiation and variable viscosity effects on free convection of a power-law nanofluid over a truncated cone in porous media with zero nanoparticles flux and internal heat generation.

Previous researches [4-16], however, have only concentrated upon the problem of impermeable surface. Alam et al. [17] studied theoretically the problem of Dufour and Soret effects on steady free convection and mass transfer flow past a semi-infinite vertical porous plate in a porous medium. Dufour and Soret effects on flow at a stagnation point with suction/injection of a Darcian fluid in a fluid-saturated porous medium are studied by Postelnicu [18]. Yih [19] examined the uniform blowing/suction and Soret/Dufour effects on heat and mass transfer by natural convection about a vertical cone in porous media: UWT/UWC.

The objective of the present work, therefore, is to extend the work of Cheng [12] and Yih [20] to investigate the effect of uniform blowing/suction on the heat and mass transfer by natural convection flow over a vertical cone subjected to uniform heat flux and uniform mass flux (UHF/UMF) embedded in porous media considering the Soret and Dufour effects.

2. Analysis

Consider the problem of the uniform blowing/suction and the Soret/Dufour effects on combined heat and mass free convection flow over a downward-pointing vertical cone of half angle γ embedded in a saturated porous medium. Figure 1 shows the flow model and physical coordinate system.

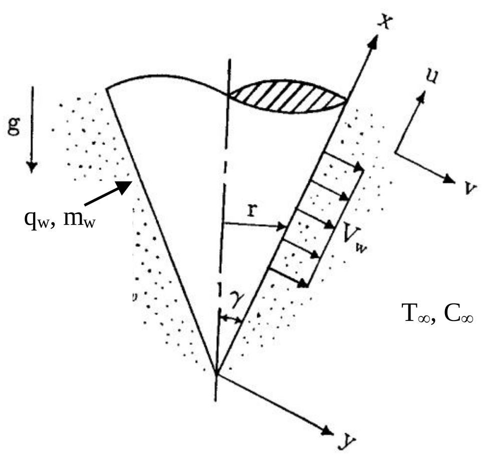

FIG. 1 The flow model and the physical coordinate system

We consider the boundary condition of

uniform heat flux q_w and uniform mass flux m_w (UHF/UMF). The ambient temperature and concentration are T_∞ and C_∞, respectively. The origin of the coordinate system is placed at the vertex of the vertical cone, where x and y are Cartesian coordinates measuring distance along and normal to the surface of vertical cone, respectively.

All the fluid properties are assumed to be constant, except for density variation in the buoyancy term. Introducing the boundary layer and Boussinesq approximations, the governing equations and the boundary conditions based on the Darcy law can be written as follows [12, 20]:

$$\frac{\partial(ru)}{\partial x}+\frac{\partial(rv)}{\partial y}=0, \tag{1}$$

$$u=-\frac{K}{\mu}\left(\frac{\partial p}{\partial x}+\rho g\cos\gamma\right), \tag{2}$$

$$v=-\frac{K}{\mu}\left(\frac{\partial p}{\partial y}-\rho g\sin\gamma\right), \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\overline{D}\frac{\partial^2 C}{\partial y^2}, \tag{4}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_M\frac{\partial^2 C}{\partial y^2}+\overline{S}\frac{\partial^2 T}{\partial y^2}, \tag{5}$$

$$\rho=\rho_\infty\left[1-\beta_T(T-T_\infty)-\beta_C(C_w-C_\infty)\right], \tag{6}$$

$$y=0:\ v=V_w,\ -k\left(\frac{\partial T}{\partial y}\right)_{y=0}=q_w,\quad -D_M\left(\frac{\partial C}{\partial y}\right)_{y=0}=m_w, \tag{7.1-3}$$

$$y\to\infty:\ u=0,\ T=T_\infty,\ C=C_\infty. \tag{8.1-3}$$

Here, u and v are the Darcian velocities in the x- and y- directions; g is the gravitational acceleration; K is the permeability of the porous medium; p is the pressure; ρ and μ are the density and absolute viscosity, respectively; T and C are the volume-averaged temperature and concentration, respectively; α and D_M are the equivalent thermal diffusivity and mass diffusivity, respectively; $\overline{D}$ and $\overline{S}$ are the Dufour coefficient and Soret coefficient of the porous medium, respectively; β_T and β_C are the thermal and concentration expansion coefficients of the fluid, respectively; V_w is the uniform blowing/suction velocity; k is the thermal conductivity of the saturated porous medium.

We assumed the boundary layer to be sufficiently thin in comparison with the local radius of the vertical cone. The local radius to a point in the boundary layer, therefore, can be replaced by the radius of the vertical cone r, i.e., r = x sinγ.

The stream function ψ is defined by

$$ru=\partial\psi/\partial y\ \text{ and }\ rv=-\partial\psi/\partial x, \tag{9}$$

therefore, the continuity equation is automatically satisfied.

We now pay attention to governing equations (2) and (3). If we do the cross-differentiation $(\partial u/\partial y-\partial v/\partial x)$, then the pressure terms in equations (2) and (3) can be eliminated. Further, with the help of the equation (6), boundary layer approximation $(\partial/\partial x \ll \partial/\partial y)$, and assuming that $g\cos\gamma$ and $g\sin\gamma$ are of the same order of magnitude, then we can obtain

$$\frac{\partial u}{\partial y}=\frac{g\cos\gamma K}{\nu}\left(\beta_T\frac{\partial T}{\partial y}+\beta_C\frac{\partial C}{\partial y}\right). \tag{10}$$

Here, ν is the kinematic viscosity and $\nu=\mu/\rho_\infty$.

Invoking the following dimensionless variables:

$$\xi=\frac{2V_w x}{\alpha Ra_x^{1/3}} \tag{11.1}$$

$$\eta=\frac{y}{x}Ra_x^{1/3} \tag{11.2}$$

$$f(\xi,\eta)=\frac{\psi}{\alpha r Ra_x^{1/3}} \tag{11.3}$$

$$\theta(\xi,\eta)=\frac{(T-T_\infty)kRa_x^{1/3}}{q_w x} \tag{11.4}$$

$$\phi(\xi,\eta)=\frac{(C-C_\infty)D_M Ra_x^{1/3}}{m_w x} \tag{11.5}$$

$$Ra_x=\frac{g\cos\gamma\beta_T K q_w x^2}{\nu\alpha k} \tag{11.6}$$

ξ is the blowing/suction parameter. For the case of blowing, $V_w > 0$ and hence $\xi > 0$. On the other hand, for the case of suction, $V_w < 0$ and hence $\xi < 0$. η is the pseudo–similarity variable, the range of η is $6 \le \eta \le 16$ .f is the dimensionless stream function, θ is the dimensionless temperature function, ϕ is the dimensionless concentration function, and Ra_x is the Rayleigh number in the porous media.

By substituting equation (11) into equations (1), (10), (4)-(5), (7)-(8), we obtain

$$f'=\theta+N\phi, \tag{12}$$

$$\theta''+\frac{5}{3}f\theta'-\frac{1}{3}f'\theta+D\phi''=\frac{1}{3}\xi\left(f'\frac{\partial\theta}{\partial\xi}-\theta'\frac{\partial f}{\partial\xi}\right). \tag{13}$$

$$\frac{1}{Le}\phi''+\frac{5}{3}f\phi'-\frac{1}{3}f'\phi+S\theta''=\frac{1}{3}\xi\left(f'\frac{\partial\phi}{\partial\xi}-\phi'\frac{\partial f}{\partial\xi}\right). \tag{14}$$

The boundary conditions are defined as follows:

$$\eta=0:\ f=-\frac{\xi}{4},\ \theta'=-1,\ \phi'=-1, \tag{15}$$

$$\eta\to\infty:\ \theta=0,\ \phi=0. \tag{16}$$

Equation (12) can be obtained by integrating equation (10) once and with the aid of boundary equation (8.1-3).

In addition, in terms of the new variables, the Darcian velocities in x- and y- directions are, respectively, given by

$$u=\frac{\alpha Ra_x^{2/3}}{x}f', \tag{17}$$

$$v=-\frac{\alpha Ra_x^{1/3}}{3x}\left(5f+\xi\frac{\partial f}{\partial\xi}-\eta f'\right). \tag{18}$$

where primes denote differentiation with respect to η.

Besides, the buoyancy ratio N, the Lewis number Le, the Dufour parameter D, and the Soret parameter S are, respectively, defined as followed:

$$N=\frac{\beta_C m_w k}{\beta_T q_w D_M},\qquad Le=\frac{\alpha}{D_M}. \tag{19}$$

$$D=\frac{\bar{D}m_w k}{\alpha q_w D_M},\qquad S=\frac{\bar{S}q_w D_M}{\alpha m_w k}. \tag{20}$$

The results of practical interest in many applications are both heat and mass transfer rates. The heat and mass transfer rates are expressed in terms of the local Nusselt number Nu_x and the local Sherwood number Sh_x respectively, which are basically defined as followed:

$$Nu_x=\frac{h_x x}{k}=\frac{q_w x}{(T_w-T_\infty)k}. \tag{21}$$

$$Sh_x=\frac{h_{m,x}x}{D_M}=\frac{m_w x}{(C_w-C_\infty)D_M}. \tag{22}$$

With the aid of equations (11.2, 11.4-6), the local Nusselt number Nu_x and the local Sherwood number Sh_x in terms of $Ra_x^{1/3}$ are, respectively, obtained by

$$\frac{Nu_x}{Ra_x^{1/3}}=\frac{1}{\theta(\xi,0)}. \tag{23}$$

$$\frac{Sh_x}{Ra_x^{1/3}}=\frac{1}{\phi(\xi,0)}. \tag{24}$$

It may be noticed that for $\xi = 0$ (impermeable), equations (12)-(16) are reduced to those of Cheng [12] where a similar solution was obtained previously. For the case of D = S = 0, equations (12)-(16) are reduced to those of

Yih [20] where a non-similar solution was obtained previously. For the case of ξ = N = D = S = 0, equations (12)-(16) are reduced to those of Cheng et al. [21] where a similar solution was obtained previously. It is also apparent that for N = D = S = 0, equations (12)-(16) are reduced to those of Yih [22] where a non-similar solution was obtained previously.

3. Numerical Method

The present analysis integrates the system of equations (12)-(16) by the implicit finite difference approximation together with the modified Keller box method of Cebeci and Bradshaw [23]. To begin with, the partial differential equations are first converted into a system of five first-order equations. Then these first-order equations are expressed in finite difference forms and solved along with their boundary conditions by an iterative scheme. This approach gives a better rate of convergence and reduces the numerical computational times.

Computations were carried out on a personal computer with $\Delta\xi = 0.1$; the first step size $\Delta\eta_1 = 0.01$. The variable grid parameter is chosen 1.01 and the value of $\eta_\infty = 16$. The iterative procedure is stopped to give the final temperature and concentration distributions when the errors in computing the $|\theta_w|$ and $|\phi_w|$ in the next procedure become less than 10^{-5}.

4. Results and Discussion

In order to verify the accuracy of our present method, we have compared our results with those of Cheng et al. [21], Yih [22, 24], and Cheng [12]. Table 1 shows the comparison of the values of $\theta(\xi,0)$ for various values of ξ with N = D = S = 0. Tables 2 and 3 list the comparison of the values of $\theta(0,0)$ and $\phi(0,0)$ for various values of N and Le with D = S = 0, respectively. The comparisons in all the above cases are found to be in excellent agreement, as shown in Tables 1-3.

Table 1 Comparison of the values of $\theta(\xi,0)$ for various values of ξ with N = D = S = 0.

ξ	$\theta(\xi,0)$		
	Cheng et al. [21]	Yih [22]	Present
-2	—	0.7198	0.7197
0	1.0562	1.0564	1.0564
2	—	1.4272	1.4272

Table 2 Comparison of the values of $\theta(0,0)$ for various values of N and Le with D = S = 0.

N	Le	$\theta(0,0)$		
		Yih [24]	Cheng [12]	Present
4	1	0.6178	0.6178	0.6178
4	10	0.9490	0.9488	0.9489
4	100	1.0416	1.0414	1.0415
1	1	0.8385	0.8384	0.8385
1	10	1.0211	1.0210	1.0211
1	100	1.0523	1.0521	1.0522
0	1	1.0564	1.0563	1.0564
0	10	1.0564	1.0563	1.0564
0	100	1.0564	1.0563	1.0564

Table 3 Comparison of the values of $\phi(0,0)$ for various values of N and Le with D = S = 0.

N	Le	$\phi(0,0)$		
		Yih [24]	Cheng [12]	Present
4	1	0.6178	0.6178	0.6178
4	10	0.2273	0.2274	0.2274
4	100	0.0781	0.0784	0.0782
1	1	0.8385	0.8384	0.8385
1	10	0.2618	0.2619	0.2618
1	100	0.0829	0.0832	0.0830
0	1	1.0564	1.0563	1.0564
0	10	0.2804	0.2805	0.2804
0	100	0.0849	0.0853	0.0850

For the purpose of the comparison with the future study, Tables 4 and 5 show the values of $\theta(\xi,0)$ and $\phi(\xi,0)$ for various values of N, Le, D and S, respectively.

Table 4 The values of $\theta(\xi,0)$ for various values of N, Le, D and S.

N	Le	D	S	$\theta(\xi,0)$		
				$\xi=2$	$\xi=0$	$\xi=-2$
4	5	0	0.1	0.9545	0.8130	0.6315
4	5	0.1	0.1	0.9976	0.8624	0.6789
1	5	0.1	0.1	1.2494	1.0143	0.7426
1	1	0.1	0.1	1.0908	0.8655	0.6553
1	1	0.1	0	1.1057	0.8789	0.6644

Table 5 The values of $\phi(\xi,0)$ for various values of N, Le, D and S.

N	Le	D	S	$\phi(\xi,0)$		
				$\xi=2$	$\xi=0$	$\xi=-2$
4	5	0	0.1	0.5510	0.3605	0.2204
4	5	0.1	0.1	0.5449	0.3541	0.2170
1	5	0.1	0.1	0.7610	0.4272	0.2326
1	1	0.1	0.1	1.0908	0.8655	0.6553
1	1	0.1	0	1.0565	0.8258	0.6141

Numerical results are presented for the buoyancy ratio N ranging from 1 to 10, the Lewis number Le ranging from 1 to 5, the Dufour parameter D ranging from 0 to 0.3 and the Soret parameter S ranging from 0 to 0.3, and the blowing/suction parameter ξ ranging from -2 to 2.

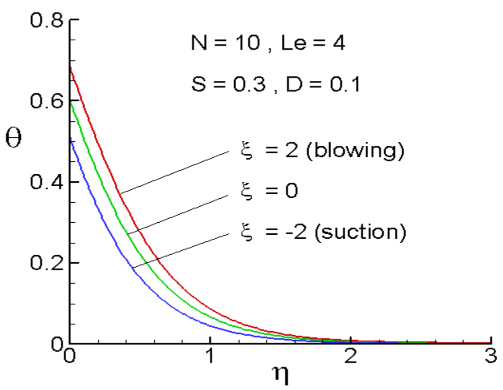

FIG. 2 The dimensionless temperature profiles for three values of the blowing/suction parameter

Figures 2 and 3 show the dimensionless temperature and concentration profiles for three values of the blowing/suction parameter ξ (ξ = -2, 0 and 2) with N = 10, Le = 4, S = 0.3, D = 0.1, respectively. From these two figures, we can find that the dimensionless temperature and concentration profiles decrease monotonically from the surface of the vertical cone to the ambient. Both the dimensionless surface temperature $\theta(\xi,0)$ and the dimensionless surface concentration $\phi(\xi,0)$ decrease for the case of suction. However, this trend reversed for the case of blowing.

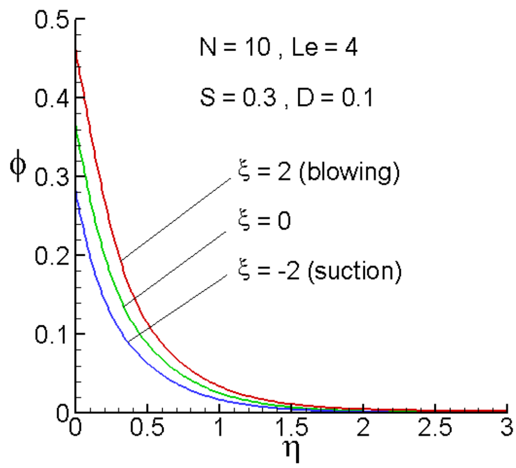

FIG. 3 The dimensionless concentration profiles for three values of the blowing/suction parameter

The dimensionless temperature and concentration profiles for three values of the Dufour parameter D (D = 0.1, 0.2 and 0.3) with N = 4, Le = 4, S = 0.3, ξ = -2 are shown in Figs. 4 and 5, respectively. Increasing the Dufour parameter D increases the dimensionless surface temperature. Whereas, enhancing the Dufour parameter D decreases the dimensionless surface concentration.

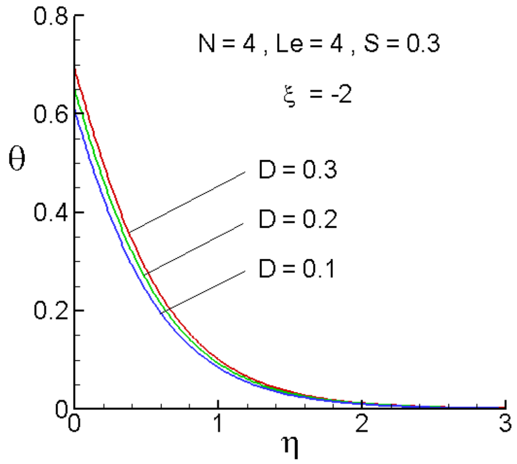

FIG. 4 The dimensionless temperature profiles for three values of the Dufour parameter

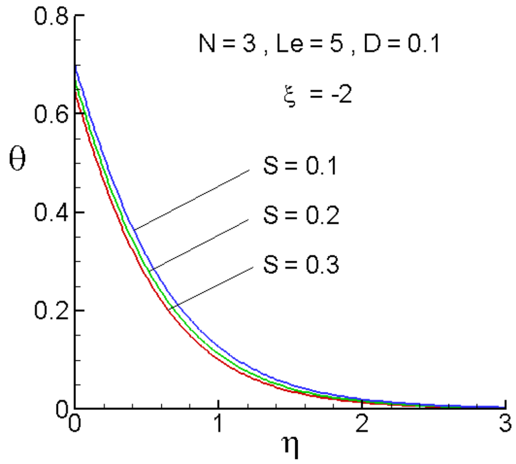

FIG. 6 The dimensionless temperature profiles for three values of the Soret parameter

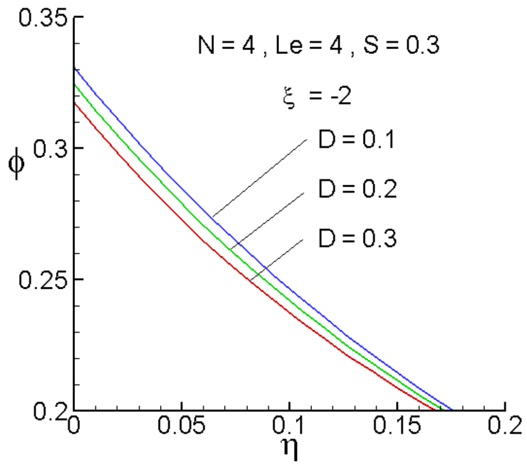

FIG. 5 The dimensionless concentration profiles for three values of the Dufour parameter

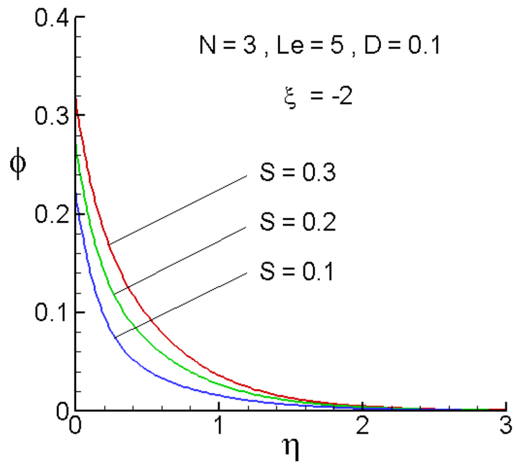

FIG. 7 The dimensionless concentration profiles for three values of the Soret parameter

Figures 6 and 7 present the dimensionless temperature and concentration profiles for three values of the Soret parameter S (S = 0.1, 0.2 and 0.3) with N = 3, Le = 5, D = 0.1, ξ = -2, respectively. In Fig. 6, the dimensionless surface temperature decreases as the Soret parameter S increases. On the contrary, increasing the Soret parameter S increases the dimensionless surface concentration, as presented in Fig. 7.

Figs. 8 and 9 illustrates the local Nusselt number $Nu_x/Ra_x^{1/3}$ and the local Sherwood number $Sh_x/Ra_x^{1/3}$ as functions of the blowing/suction parameter ξ for two values of the Dufour parameter (D = 0.1 and 0.2), two values of the buoyancy ratio (N = 4 and 10) with Le = 4, S = 0.3, respectively. In general, it has been found that both the local Nusselt number and the local Sherwood number increase owing to the case of suction, i.e., $\xi < 0$. This is because for the case of suction decreases both the dimensionless surface temperature $\theta(\xi,0)$ and the dimensionless surface concentration $\phi(\xi,0)$, as shown in Figs. 2 and 3. This trend reversed for the case of blowing.

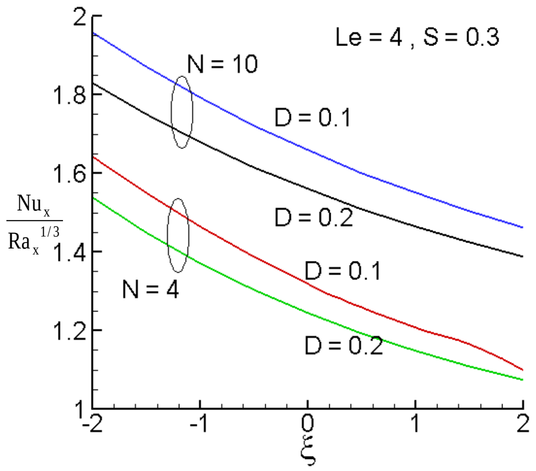

FIG. 8 Effect of Dufour parameter and the buoyancy ratio on the local Nusselt number

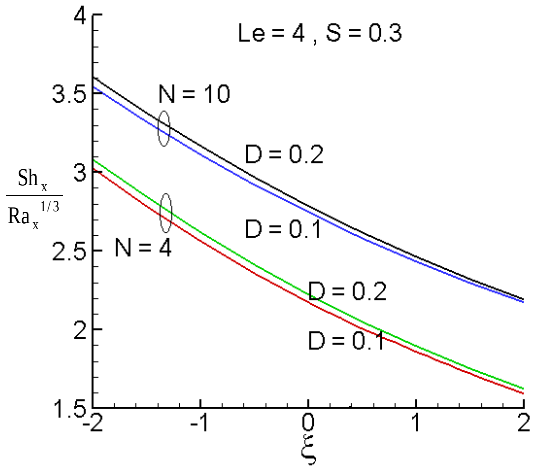

FIG. 9 Effect of Dufour parameter and the buoyancy ratio on the local Sherwood number

Enhancing the buoyancy ratio N increases the buoyancy force, accelerating the flow and decreases both the dimensionless surface temperature and concentration, thus enhances both the local Nusselt number and the local Sherwood number.

Besides, increasing the Dufour parameter tends to decrease the local Nusselt number, while it tends to increase the local Sherwood number. It is owing to the fact that increasing the Dufour parameter D increases the dimensionless surface temperature and decreases the dimensionless surface concentration, as illustrated in Figs. 4 and 5, respectively.

The local Nusselt number $Nu_x/Ra_x^{1/3}$ and the local Sherwood number $Sh_x/Ra_x^{1/3}$ as functions of the blowing/suction parameter ξ for two values of the Lewis number (Le = 2 and 5), two values of the Soret parameter (S = 0.1 and 0.2) with N = 3, D = 0.1, as shown in Figs. 10 and 11, respectively. It is found that, as the Lewis number increases, decreases the local Nusselt number and increases the local Sherwood number from the vertical cone in saturated porous media. This is due to the fact that a larger Lewis number Le is associated with a thicker thermal boundary layer and a thinner concentration boundary layer. The thicker the thermal boundary layer thickness, the smaller the local Nusselt number. The thinner the concentration boundary layer thickness, the larger the local Sherwood number.

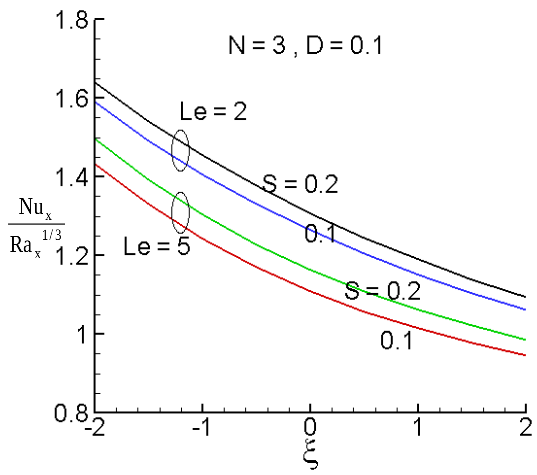

FIG. 10 Effect of Soret parameter and the Lewis number on the local Nusselt number

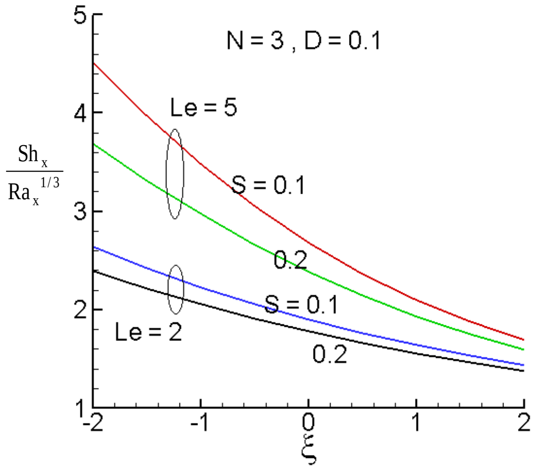

FIG. 11 Effect of Soret parameter and the Lewis number on the local Sherwood number

Moreover, as the Soret parameter S increases, the local Nusselt number tends to increase and the local Sherwood number tends to decrease. This is due to the fact when the Soret parameter S increases, the dimensionless surface temperature decreases; thereby increases the local Nusselt number, as illustrated in Fig. 6. However, increasing the Soret parameter increases the dimensionless surface concentration, as depicted in Fig. 7.

Comparing Figs. 10 and 11, the blowing/suction parameter ξ is also found to have a more pronounced effect on the local Sherwood number than the local Nusselt number.

5. Conclusions

A boundary layer analysis is presented to study the effect of the uniform blowing/suction on natural convection flow in a saturated porous medium resulting from combined heat and mass buoyancy effects adjacent to the vertical cone maintained at uniform heat flux and uniform mass flux (UHF/UMF) considering the Soret and Dufour effects. Numerical solutions are obtained for different values of the blowing/suction parameter ξ, the buoyancy ratio N, the Lewis number Le, the Soret parameter S and the Dufour parameter D. It is shown that for the case of suction (blowing) both the heat and mass transfer rates increase (decrease). It is also found that increasing the buoyancy ratio parameter increases both the local Nusselt number and the local Sherwood number. As the Lewis number increases, the local Nusselt (Sherwood) number decreases (increases). Enhancing the Dufour parameter tends to reduce the local Nusselt number and enhance the local Sherwood number. When the Soret parameter is increased, the local Nusselt number has a tendency to increase and the local Sherwood number tends to decrease.

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