International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Influence of Variable Permeability on Heat and Mass Transfer due to Free Convection Flow over a Vertical Flat Plate in Porous Medium Considering Soret and Dufour Effects

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Abstract

The influence of variable permeablity on heat and mass transfer due to free convection flow over a vertical flat plate embedded in a fluid saturated porous medium is studied in presence of heat source/sink, non-linear density temperature variation, non- linear density concentration variation, soret and dufour effect .The concentration profile is drawn for various parameters in both uniform and non-uniform permeability cases. Numerical results of rate of mass transfer for different parameters such as suction/blowing, wall temperature exponent, heat source / sink, non-linear density temperature variation as well as non- linear density concentration variation for both uniform and non-uniform permeability cases are presented in tabular form.

Keywords: Free convection; heat source / sink; non- linear density concentration; non-linear density temperature; porous medium; variable permeability.

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1. Introduction

Coupled heat and mass transfer by free convection flow in fluid saturated porous medium has attracted considerable attention in last several decades due to its many important engineering, environmental and geophysical applications. Recent books by Nield and Bejan [1] , Ingham and Pop [2] present a comprehensive account of available information in the field. Assuming the linear density temperature variation of Boussinesq's approximation. Cheng and Minkowycz [3] discussed the free convection flow in a saturated porous medium of constant permeability , when the temperature difference between the plate and the ambient fluid is large . Vajravelu and Sastri [4] discussed the non- linear density temperture variation taking into account the buoyancy force term. Convective boundary layer flows are controlled by injecting or withdrawing fluid through a porous bounding heated surface. Eichhorn [5] obtained power-law variations in surface temperature and transpiration velocity which gives a similarity solution for flow from a vertical surface. Merkin [6] has studied the effect of strong suction and blowing from general body shapes which admits a similarity solution. Vedhanayagam [7] has discussed the transformation of equations for general blowing and wall temperature variations. Lin and Yu [8] discussed the case of heated isothermal horizontal surface with transpiration . The above investigations are carried out for the fluid having uniform permeability of porous medium. To study non-uniform permeability effects, a simple exponential function of the distance from the wall was taken. Chandrasekhara [9] has discussed the similarity solution's for buoyancy-induced flows in a saturated porous medium adjacent to impermeable horizontal surfaces. Chandrasekhara [10] has incorporated the variable permeability to study the flow past and through a porous medium and has shown that the variation of porosity and permeability has great influence on velocity fields and on the rate of heat transfer . Rees and Pop [11] have studied how the variable permeability affects the flow and heat transfer from uniformly heated surface. Kabeir and Rashad [12] has discussed the influence of variable permeability on free convection over vertical flat plate embedded in a porous medium. Sharma [13] has analyzed the Soret and Dufour effects on seperation of binary fluid mixture in MHD natural convection in porous media.

The objective of this paper is to study how the variation of permeability affects the free convective boundary layer flow from a vertical flat plate embedded in a porous medium considering the effects of non-linear density temperature variation, non-linear density concentration variation and temperature dependent heat source. With this, Soret and Dufour effects are also considered in the problem.

2. Analysis

We consider steady, laminar, incompressible two-dimensional free convection flow in a fluid-saturated porous medium of variable permeability over a vertical flat plate by taking x-axis along the plate and y-axis perpendicular to it directed in the porous region. The surface temperature (T_w) of the plate is given by $T_w = T_\infty + Ax^\lambda$ where T_∞ is the temperature of the fluid far away from the plate, A being constant. The temperature of the fluid is everywhere below the boiling point. C_∞ is the concentration of the fluid far away from the plate.

We have considered following assumptions:

- The non- linear density variation is taken as

$$\rho = \rho_\infty[1 - \beta_{T_0}(T - T_\infty) - \beta_{T_1}(T - T_\infty)^2 - \beta_{C_0}(C - C_\infty) - \beta_{C_1}(C - C_\infty)^2 - \beta_{TC}(T - T_\infty)(C - C_\infty)] \qquad \ldots(1)$$

where ρ is density, β_{T_0} and β_{T_1} are volumetric coefficient of thermal expansion, β_{C_0} and β_{C_1} are coefficient of concentration expansion.

- The effect of volumetric heat source / sink term in the energy equation is not negligible.
- The fluid and porous medium are everywhere in local thermodynamic equilibrium.
- The permeability of the porous medium is given by

$$K(y) = K_\infty + (K_w - K_\infty)e^{\frac{-y}{H}} \qquad \ldots(2)$$

where K_w is the permeability of the wall , K_∞ is the permeability of the ambient and H is constant based on modified Rayleigh number Ra_x .

Under these assumptions, the governing equations are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \,, \qquad \ldots(3)$$

$$u = \frac{-K(y)}{\mu}\left[\frac{\partial p}{\partial x} + (\rho - \rho_\infty)g\right] \,, \qquad \ldots(4)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{Q}{(\rho_\infty C_p)_f}(T - T_\infty) + \frac{D_m k_T}{C_S C_P}\frac{\partial^2 C}{\partial y^2} \qquad \ldots(5)$$

and $$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} + \frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} \qquad \ldots(6)$$

where $u,\ v$ are Darcy velocity component in $x,\ y$ directions respectively, p is the constant pressure, g is the acceleration due to gravity , Q is the heat source, C_p is the specific heat at constant pressure, α is thermal diffusivity, T is the temperature of the fluid, μ is the coefficient of viscosity, k_T is thermal diffusion ratio, C_S is concentration susceptibility, C is the concentration of the fluid , T_m is mean fluid temperature and D_m is mean diffusivity.

The boundary conditions of the problem are

$$\left.\begin{array}{lll} u = 0\,, v = V_w(x),\ T = T_w\,,\ C = C_w & & \text{at } y = 0 \\ \text{and} & T \to T_\infty\,,\ C \to C_\infty & \text{as } y \to \infty \end{array}\right\} \qquad \ldots(7)$$

where $V_w(x)$ is transpiration velocity of the fluid through the surface of the plate which is positive for injection or blowing of the fluid through the plate and negative for suction or withdrawal.

We now introduce the following dimensionless variables

$$\left.\begin{aligned} &\eta = \frac{y}{x} Ra_x^{\frac{1}{2}}\ ,\ \psi = \alpha Ra_x^{\frac{1}{2}} f(\eta), \\ &\theta = \frac{T - T_\infty}{T_w - T_\infty} \ \text{ and } \ \phi = \frac{C - C_\infty}{C_w - C_\infty} \end{aligned}\right\} \qquad \ldots(8)$$

where ψ is stream function defined by

$$u = \frac{\partial \psi}{\partial y}\ ,\ v = -\frac{\partial \psi}{\partial x}$$

and $Ra_x = \frac{\rho_\infty g K_\infty \beta_{T0} (T_w - T_\infty) x}{\mu \alpha}$ is the local Rayleigh number.

If we take $H = x Ra_x^{-1/2}$,then equation (2) for permeability in non-dimensional form becomes

$$K(\eta) = K_\infty\ [1 + (\epsilon - 1) e^{-\eta}] \qquad \ldots(9)$$

where $\epsilon = \frac{K_w}{K_\infty}$ is the permeability parameter. When $\epsilon = 1$, it corresponds to uniform permeability and when $\epsilon > 1$, it corresponds to non-uniform permeability.

If we introduce the relations (8) into (4) , (5) and (6) , we get

$$f' - [1 + (\epsilon - 1) e^{-\eta}]\big[\theta(1 + \beta_T \theta) + \beta_C \theta \emptyset + \emptyset\big(\beta_{CT} + \beta_{C_1 T} \emptyset\big)\big] = 0 \qquad \ldots(10)$$

$$\theta'' + \left(\frac{\lambda + 1}{2}\right) f \theta' - (\lambda f' - \alpha_0)\theta + D_f \emptyset'' = 0 \qquad \ldots(11)$$

$$S_r \theta'' + \left(\frac{\lambda + 1}{2}\right) f \emptyset' + \frac{1}{Le} \emptyset'' = 0 \qquad \ldots(12)$$

where $\beta_T = \frac{\beta_{T1}}{\beta_{T0}} (T_w - T_\infty)$ is the non-linear density temperature parameter,

$\beta_C = \frac{\beta_{TC}}{\beta_{T0}} (C_w - C_\infty)$ is the non-linear density concentration parameter ,

$\beta_{CT} = \frac{\beta_{C0}}{\beta_{T0}} \frac{(C_w - C_\infty)}{(T_w - T_\infty)}$ is the non-linear density concentration temperature parameter and $\beta_{C_1 T} = \frac{\beta_{C1}}{\beta_{T0}} \frac{(C_w - C_\infty)^2}{(T_w - T_\infty)}$ is the non-linear density concentration square temperature parameter.

λ is the range of exponent , $D_f = \frac{D_m k_T}{\alpha C_s C_p} \frac{(C_w - C_\infty)}{(T_w - T_\infty)}$ is Dufour number,

$\alpha_0 = \frac{Qx^2}{\alpha Ra_x\,(\rho_\infty\,C_p)_f}$ is the heat source / sink parameter , $S_r = \frac{D_m k_T}{T_m \alpha}\frac{(T_w - T_\infty)}{(C_w - c_\infty)}$ is Soret number and $Le = \frac{\alpha}{D_m}$ is Lewis number.

The boundary conditions are transformed to

$$\left.\begin{aligned} f' = 0\,, f = f_w\,,\ \theta = 1\,,\ \emptyset = 1 \quad \text{at } \eta = 0 \\ \theta \to 0\,,\ \emptyset \to 0 \ \text{ as } \eta \to \infty \end{aligned}\right\} \qquad \ldots(13)$$

where $f_w = \frac{-2xV_w(x)}{\alpha(\lambda+1)Ra_x^{1/2}}$ is suction / blowing parameter which is positive for suction of the fluid and negative for injection or blowing of the fluid.

3. Results and Discussions

The ordinary differentials equations (10), (11) and (12) with the corresponding boundary conditions (13) have been solved numerically by using bvp4c solver of MATLAB. From the process of numerical computation , the local Sherwood number which is proportional to $-\emptyset'(0)$ is worked out and their numerical values are presented in tabular form. Numerical calculations for $\emptyset'$ have been carried out by taking various values of parameters ϵ , λ , α_0 , Le , D_f , f_w , β_T , β_C , β_{CT} , β_{C_1T} and S_r . Several cases are considered:

Case1: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\epsilon = (1.0, 1.25, 1.5)$

Case2: $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\lambda = (0.0, 0.2, 0.5)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case3: $\lambda = 0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\alpha_0 = (-0.5, 0.0, 0.5)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case4: $\lambda = 0.2$, $\alpha_0 = -0.2$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $Le = (1, 2, 3)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case5: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $D_f = (0.0, 0.2, 0.4)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case6: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $f_w = (-0.2, 0.0, 0.2)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case7: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\beta_T = (-0.5, 0.0, 0.5)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case8: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\beta_C = (1, 2, 3)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case9: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{C_1T} = 1$ and $\beta_{CT} = (1, 2, 3)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case10: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$ and $\beta_{C_1T} = (1, 2, 3)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Case11: $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $S_r = (0.2, 0.4, 0.6)$ with (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

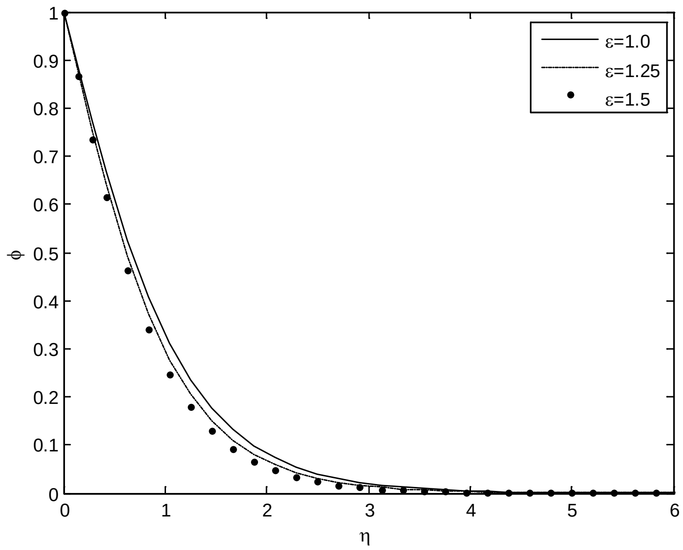
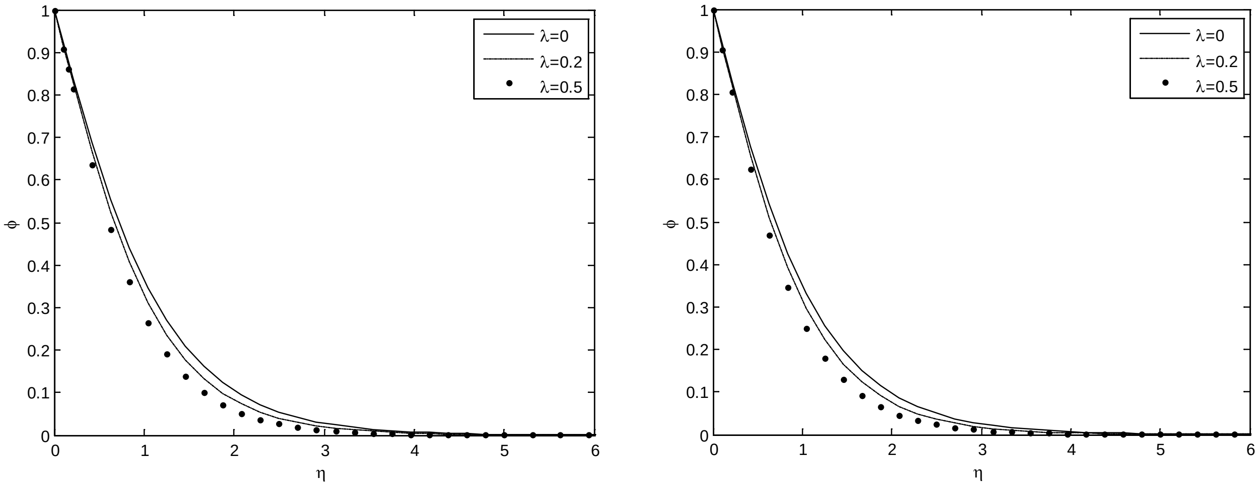


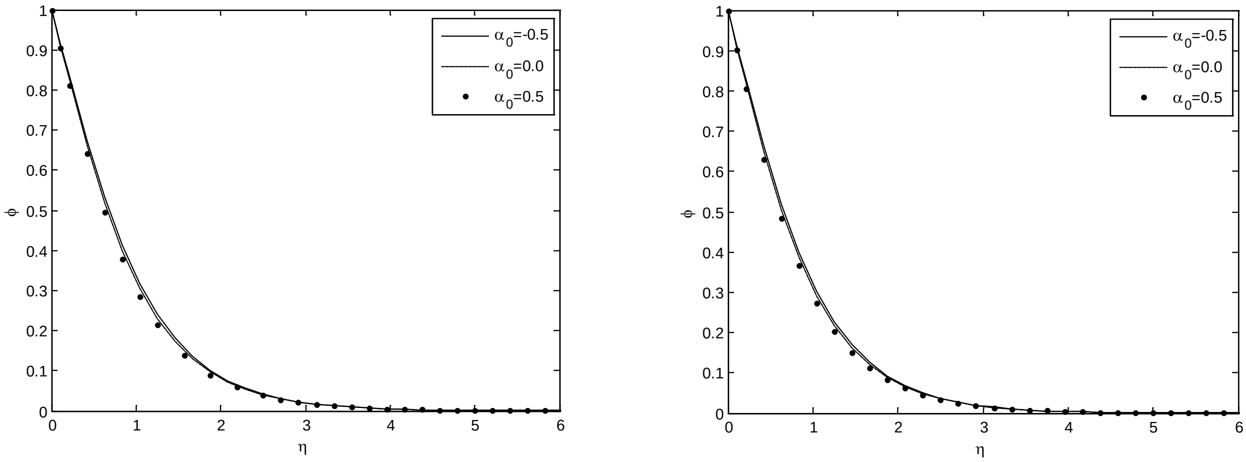
Fig. 1: Effect of Variation of permeability on concentration profile with

$\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ and $\epsilon = (1.0, 1.25, 1.5)$



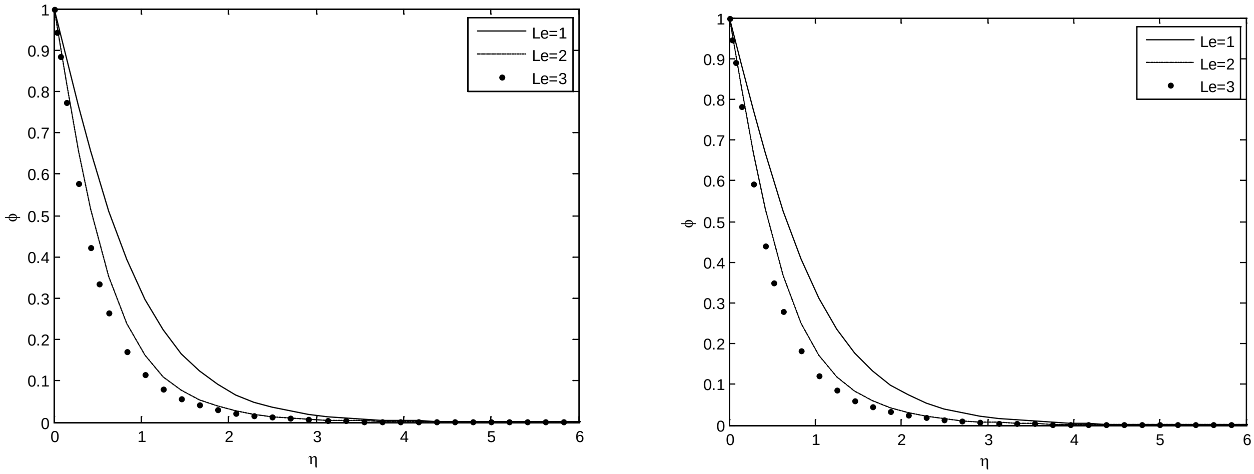
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 2: Concentration profile for $\lambda = (0.0, 0.2, 0.5)$ with $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



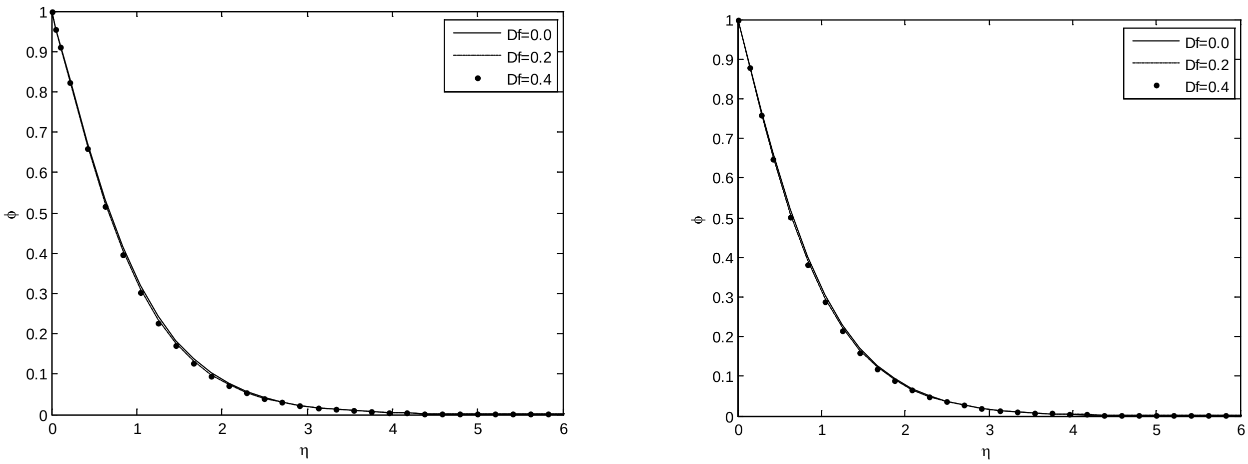
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 3: Concentration profile for $\alpha_0 = (-0.5, 0.0, 0.5)$ with $\lambda = 0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



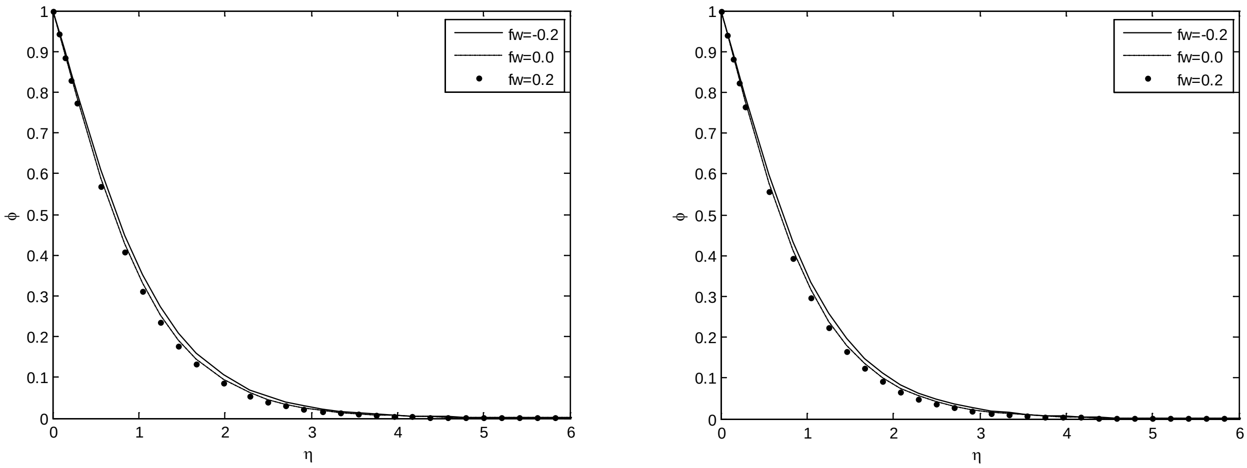
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 4: Concentration profile for $Le = (1, 2, 3)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



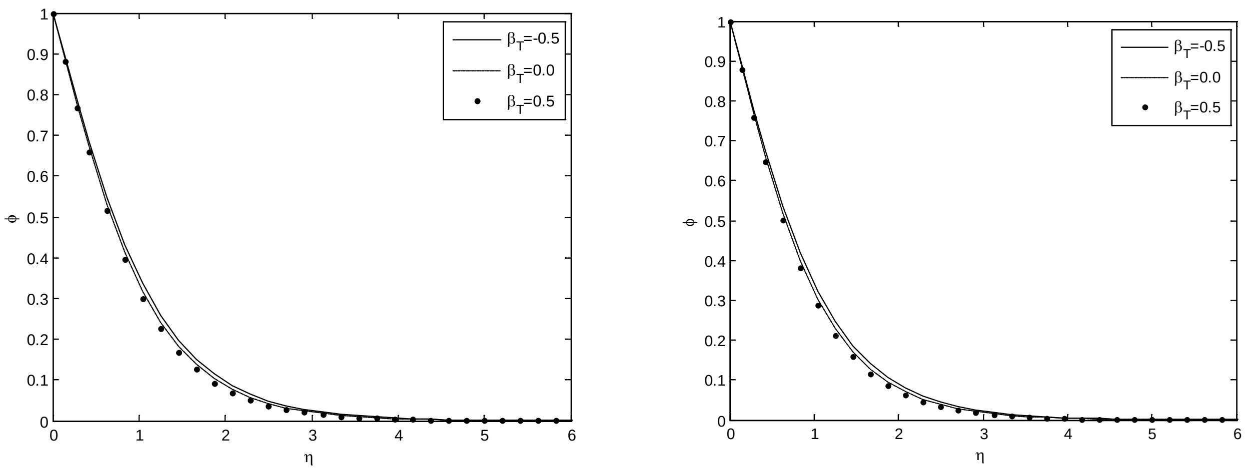
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 5: Concentration profile for $D_f = (0.0, 0.2, 0.4)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



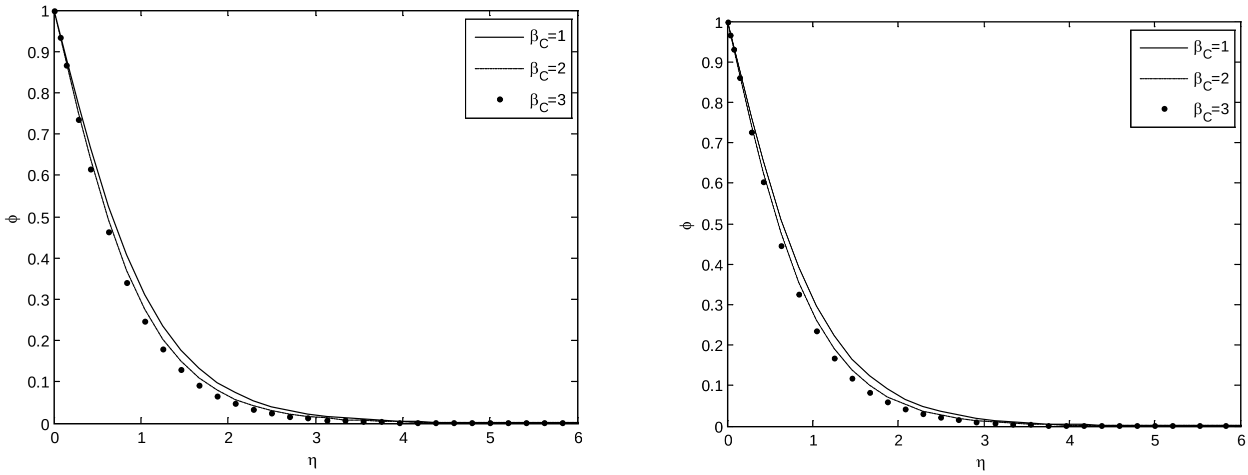
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 6: Concentration profile for $f_w = (-0.2, 0.0, 0.2)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



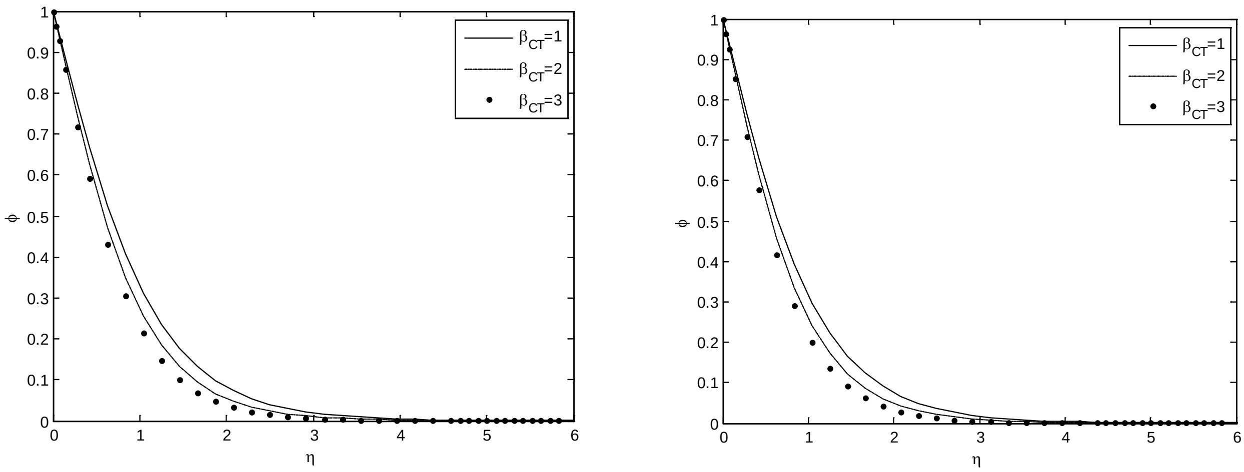
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 7: Concentration profile for $\beta_T = (-0.5, 0.0, 0.5)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



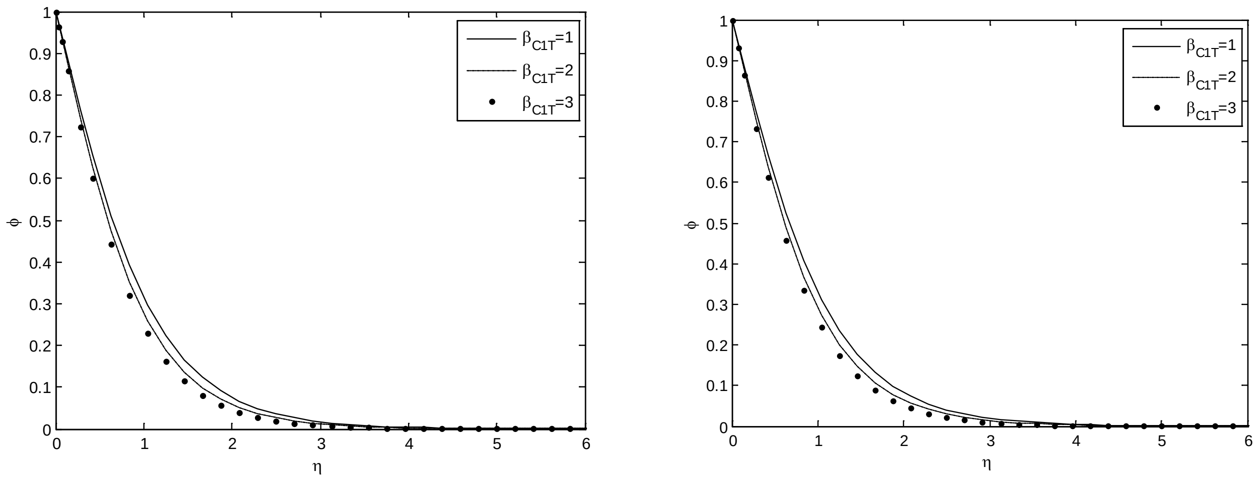
(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 8: Concentration profile for $\beta_C = (1, 2, 3)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



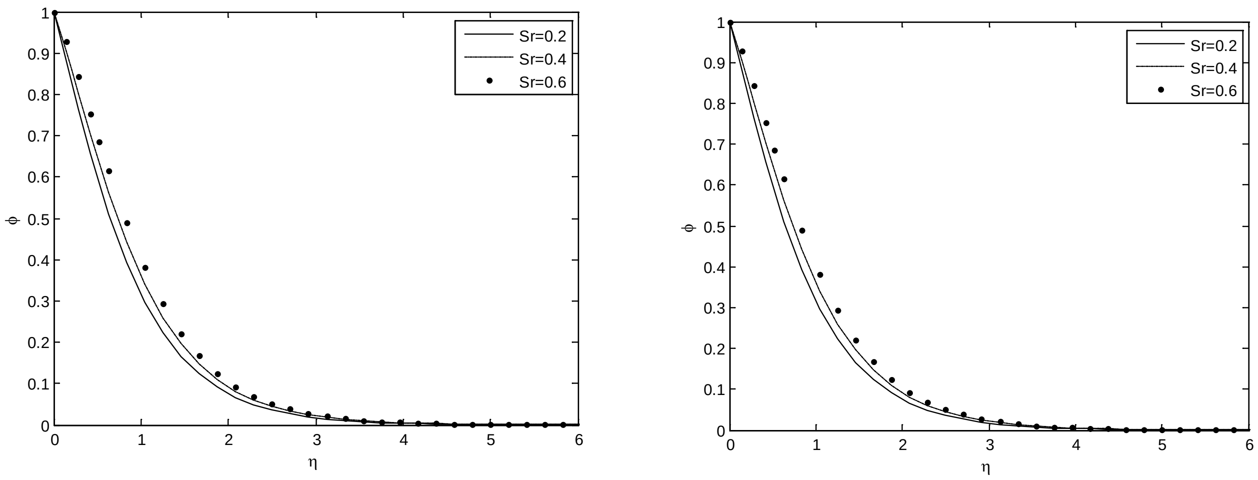
$(a)\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 9: Concentration profile for $\beta_{CT} = (1, 2, 3)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 10: Concentration profile for $\beta_{C_1T} = (1, 2, 3)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $S_r = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$



(a) $\epsilon = 1.0$ (b) $\epsilon = 1.1$

Fig. 11: Concentration profile for $S_r = (0.2, 0.4, 0.6)$ with $\lambda = 0.2$, $\alpha_0 = -0.2$, $Le = 1$, $D_f = 0.2$, $f_w = 0.2$, $\beta_T = 0.2$, $\beta_C = 1$, $\beta_{CT} = 1$, $\beta_{C_1T} = 1$ considering (a) $\epsilon = 1.0$ and (b) $\epsilon = 1.1$

Fig (1) depicts the concentration variation against η for various values of variable permeability parameter. From Fig (1) it reveals that concentration decreases with increase in the permeability parameter , however this variation is found to be very small. It is observed from Fig (1) that the concentration decreases exponentially from its maximum value at the plate to its minimum value at the end of the boundary layer.

For both, uniform and non-uniform permeability, cases (i.e. for $\epsilon = 1.0$ and $\epsilon = 1.1$), it is observed from Figs. (2)-(11) that concentration decreases with the increase in the values of parameters λ, α_0, Le, D_f, f_w, β_T, β_C, β_{CT}, β_{C_1T} and increases with increase in S_r. From Figs. (2) – (11), it is also observed that the concentration decreases exponentially from its maximum value at the plate to its minimum value at the end of the boundary layer for both uniform and non-uniform permeability cases.

4. Conclusions

From this paper, we can conclude as obvious from Table 1 and Table 2, that the rate of mass transfer in non-uniform permeability case is higher than that of uniform permeability case. In both cases of uniform and non-uniform permeability, the rate of mass transfer increases in magnitude with increase in heat source / sink parameter (α_0), non-linear density temperature parameter variation (β_T), non-linear density concentration parameter variation (β_C), and Dufour coefficient (D_f) but decreases in magnitude with increase in Soret coeefficient (S_r). As the permeability parameter increases, the rate of mass transfer increases in magnitude at any chosen values of α_0, β_T, β_C and D_f but decreases in magnitude at any chosen value of S_r.

TABLE 1 : The values of rate of mass transfer in terms of local Sherwood number $-\emptyset'(0)$ for selected values of λ, α_0, Le, D_f, S_r, f_w, β_T, β_C, β_{CT} and β_{C_1T} in the uniform permeability case ($\epsilon = 1.0$).

λ	α_0	Le	D_f	S_r	f_w	β_T	β_C	β_{CT}	β_{C_1T}	$-\emptyset'(0)$
0.0	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.7867
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.5	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8770
0.2	-0.5	1	0.2	0.2	0.2	0.2	1	1	1	0.7873
0.2	0.0	1	0.2	0.2	0.2	0.2	1	1	1	0.8446
0.2	0.5	1	0.2	0.2	0.2	0.2	1	1	1	0.9210
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	2	0.2	0.2	0.2	0.2	1	1	1	1.2404
0.2	-0.2	3	0.2	0.2	0.2	0.2	1	1	1	1.5938
0.2	-0.2	1	0.0	0.2	0.2	0.2	1	1	1	0.7978
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.4	0.2	0.2	0.2	1	1	1	0.8431
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.2	0.4	0.2	0.2	1	1	1	0.6418
0.2	-0.2	1	0.2	0.6	0.2	0.2	1	1	1	0.4494
0.2	-0.2	1	0.2	0.2	-0.2	0.2	1	1	1	0.7012
0.2	-0.2	1	0.2	0.2	0.0	0.2	1	1	1	0.7594
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.2	0.2	0.2	-0.5	1	1	1	0.7687
0.2	-0.2	1	0.2	0.2	0.2	0.0	1	1	1	0.8057

0.2	-0.2	1	0.2	0.2	0.2	0.5	1	1	1	0.8412
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.2	0.2	0.2	0.2	2	1	1	0.8942
0.2	-0.2	1	0.2	0.2	0.2	0.2	3	1	1	0.9625
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	2	1	0.9307
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	3	1	1.0282
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8201
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	2	0.9003
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	3	0.9733

TABLE 2 : The values of rate of mass transfer in terms of local Sherwood number $-\emptyset'(0)$ for selected values of λ, α_0, Le, D_f, S_r, f_w, β_T, β_C, β_{CT} and β_{C_1T} in the non-uniform permeability case ($\epsilon = 1.1$)

λ	α_0	Le	D_f	S_r	f_w	β_T	β_C	β_{CT}	β_{C_1T}	$-\emptyset'(0)$
0.0	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8155
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.5	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.9084
0.2	-0.5	1	0.2	0.2	0.2	0.2	1	1	1	0.8177
0.2	0.0	1	0.2	0.2	0.2	0.2	1	1	1	0.8736
0.2	0.5	1	0.2	0.2	0.2	0.2	1	1	1	0.9471
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	2	0.2	0.2	0.2	0.2	1	1	1	1.2880
0.2	-0.2	3	0.2	0.2	0.2	0.2	1	1	1	1.6562
0.2	-0.2	1	0.0	0.2	0.2	0.2	1	1	1	0.8265
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	1	0.4	0.2	0.2	0.2	1	1	1	0.8738
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	1	0.2	0.4	0.2	0.2	1	1	1	0.6652
0.2	-0.2	1	0.2	0.6	0.2	0.2	1	1	1	0.4661
0.2	-0.2	1	0.2	0.2	-0.2	0.2	1	1	1	0.7303
0.2	-0.2	1	0.2	0.2	0.0	0.2	1	1	1	0.7888
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8498
0.2	-0.2	1	0.2	0.2	0.2	-0.5	1	1	1	0.7957
0.2	-0.2	1	0.2	0.2	0.2	0.0	1	1	1	0.8347
0.2	-0.2	1	0.2	0.2	0.2	0.5	1	1	1	0.8720

0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	1	0.2	0.2	0.2	0.2	2	1	1	0.9294
0.2	-0.2	1	0.2	0.2	0.2	0.2	3	1	1	0.9990
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	2	1	0.9649
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	3	1	1.0666
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	1	0.8497
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	2	0.9337
0.2	-0.2	1	0.2	0.2	0.2	0.2	1	1	3	1.0100

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