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Coupling-Diffusive Effects on Thermosolutal Buoyancy Convection in a Horizontal Cavity

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COUPLING–DIFFUSIVE EFFECTS ON THERMOSOLUTAL BUOYANCY CONVECTION IN A HORIZONTAL CAVITY

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Coupling–diffusive effects on thermosolutal buoyancy convection with Soret and Dufour effects in a horizontal cavity are investigated numerically. The problem is formulated using a coupling–diffusive model for thermosolutal buoyancy convection and is solved by the SIMPLE algorithm with the QUICK scheme in a nonuniform staggered grid system. The results show that thermal and solutal buoyancy primarily dominate the structure of the velocity field and that the inflexion points of flow pattern transform as Rayleigh number or buoyancy ratio increases. The parametric study shows that the heat and mass transfer of thermosolutal convection are enhanced as Rayleigh number or buoyancy ratio increases. Soret and Dufour effects have a linear influence on heat and mass transfer in a horizontal cavity so that the coupling–diffusive effects cannot be ignored, especially under high Rayleigh numbers.

1. INTRODUCTION

Thermosolutal buoyancy convection simultaneously induced by temperature and concentration gradients can generate many intriguing heat and mass transfer phenomena. This has been an intensive research topic from both the theoretical and practical points of view due to its importance to the indoor environment in many areas, from ventilation [1–3] to industrial manufacture [4, 5]. During convective and diffusive processes, thermal and concentration buoyancy not only drives fluid flow but also exhibits a complex coupling–diffusive interaction (Soret and Dufour effects) [6, 7] where temperature and concentration gradients have significant effects on both temperature and concentration distribution. Over the last few decades, various advanced models and methods (experimental and numerical) have been explored to better understand the physical mechanism of the complex thermosolutal convective and diffusive processes for different applications.

Initially, thermosolutal buoyancy convection and diffusion were considered as pure convection based on negligible coupling–diffusive interaction. Kamotani et al.

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In regard to thermosolutal buoyancy convection, the effect of coupling–diffusive interaction on temperature and concentration distributions cannot be ignored in the investigation of double-diffusive convection where temperature and concentration gradients coexist. Recently further studies on thermosolutal buoyancy convection have been carried out to investigate coupling–diffusive interaction in physical models. Trevisan and Bejan [16] investigated convection and diffusion in a rectangular slot with uniform heat flux along the vertical sides while taking coupling–diffusive interaction into account. Van der Zanden [17] developed a convective model incorporating Soret and Dufour effects in heterogeneous media, and provided effective heat- and mass-flux formulas. Malashetty and Gaikwad [18] investigated the effect of coupling–diffusive interaction on double-diffusive convection in an unbounded vertically stratified two-component system driven by horizontal thermal and solutal buoyancy. Ouriemi et al. [19] proposed an analytical model of thermosolutal convection in a horizontal shallow cavity with a binary fluid based on parallel flow approximation and studied the effect of Rayleigh number on system flow to predict the onset of supercritical and subcritical convection by the numerical method. Kim et al. [20] theoretically analyzed convective instability in binary nanofluids resulting from coupling–diffusive interaction using linear stability theory in

### NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$c$</td>
<td>concentration, kg/m$^3$</td>
</tr>
<tr>
<td>$C$</td>
<td>dimensionless concentration</td>
</tr>
<tr>
<td>$D$</td>
<td>diffusion coefficient, m$^2$/s</td>
</tr>
<tr>
<td>$D_f$</td>
<td>Dufour coefficient</td>
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<td>gravitational acceleration, m$^2$/s</td>
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<tr>
<td>$Le$</td>
<td>Lewis number</td>
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<tr>
<td>$N_{Ce}$</td>
<td>buoyancy ratio</td>
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<tr>
<td>$Nu$</td>
<td>average Nusselt number</td>
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<td>dimensionless pressure</td>
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<td>Prandtl number</td>
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<td>Rayleigh number</td>
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<tr>
<td>$Sh$</td>
<td>average Sherwood number</td>
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<tr>
<td>$S_T$</td>
<td>Soret coefficient</td>
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<td>$S_c$</td>
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<tr>
<td>$\tau$</td>
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<tr>
<td>$\kappa_{TC}$</td>
<td>Dufour coefficient, m$^5$/C$^1$/kg/C$^0$/s</td>
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<td>$\nu$</td>
<td>kinematical viscosity, m$^2$/s</td>
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### Subscripts

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<td>0</td>
<td>initial condition</td>
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<td>$h$</td>
<td>high-temperature or -concentration</td>
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<tr>
<td>$l$</td>
<td>low-temperature or -concentration</td>
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</table>

Subscripts 0 initial condition $h$ high-temperature or -concentration $l$ low-temperature or -concentration
a one-fluid model. Khadiri et al. [21] studied numerically the Soret effect on thermosolutal convection in a two-dimensional square cavity filled with a saturated Darcy porous medium. Bhuveswari et al. [22] investigated double-diffusive mixed convection with Soret effect in a two-sided lid-driven cavity where the vertical walls moved at a constant velocity.

More and more successful models and methods have been developed to simulate heat and mass transfer under thermosolutal buoyancy convection with different flow media, geometrical regions, and boundary conditions. Meanwhile, different situations and conditions show major discrepancy in flow structure [7, 16], as well as heat and mass transfer [5, 9, 11]. For the horizontal cavity widely used in laser fabrication [23] and the refrigeration industry [24, 25], Ong and Thome [24] studied the heat transfer and flow patterns of thermosolutal convection for three refrigerants in a horizontal circular channel. Henderson et al. [25] investigated experimentally thermosolutal convection of R-134a-based nanofluids in a horizontal tube under boiling condition. Goldstein et al. [26] performed experiments on thermosolutal convection adjacent to horizontal circular, square, and 7:1 rectangular planes using the naphthalene sublimation technique, and overall mass transfer coefficients and Sherwood numbers were obtained as functions of Rayleigh number. Kandlikar [27] developed a simple correlation for predicting saturated two-phase flow-boiling heat transfer inside horizontal and vertical tubes based on nucleate boiling and thermosolutal convective mechanisms. An approximate solution for steady-state thermosolutal convection along a semi-infinite horizontal plate was obtained by Anjalidevi and Kandasamy [28] considering chemical reactions using the numerical technique.

For complex thermosolutal convection in a horizontal cavity, experimental [25, 26] and numerical [27, 28] studies have been carried out using a variety of flow patterns under different conditions. However, Soret and Dufour effects due to temperature and concentration gradients [6, 7] in horizontal cavity convection were not taken into consideration. To predict more accurately heat and mass transfer during thermosolutal convection in a horizontal cavity, Wang et al. [29] developed a numerical model of high precision for thermosolutal convection with Soret and Dufour effects and investigated qualitatively the flow structure of the convection.

To better understand thermosolutal buoyancy convection in a horizontal cavity, coupling–diffusive effects on thermosolutal convection are investigated systematically in the present study. Coupling–diffusive effects on the flow patterns and heat and mass transfer of convection are investigated quantitatively under varying Rayleigh number and buoyancy ratio of thermal and solutal buoyancy in a horizontal cavity.

2. PROBLEM STATEMENT AND FORMULATION

Figure 1 shows the physical model for thermosolutal buoyancy convection in a horizontal cavity. A horizontal cavity with 1:4 aspect ratio is subject to different uniform temperatures and concentrations on its horizontal (upper and lower) walls while the vertical walls are adiabatic and impermeable (i.e., the temperature and concentration are $T_h, c_h$ on the upper wall and $T_l, c_l$ on the lower wall). Initially, the cavity is filled with a binary medium of air and solute at a uniform temperature of $T_0$ and uniform concentration of $c_0$. Thermal and solutal buoyancy coexist due to
the temperature and concentration gradients, and thermosolutal buoyancy convection and diffusion in the horizontal cavity occur.

It is assumed that there is no chemical reaction, heat generation, or thermal radiation. The medium of air and solute in the cavity is Newtonian fluid, and wall-slip condition applies to the wall. Meanwhile, the properties of the medium are constant and independent of time, temperature, and concentration except for the density of buoyancies term in momentum equations, which satisfies the Boussinesq approximation:

$$q = q_0 + \frac{1}{ho_0 c_0} (\beta_T T_0 - \beta_c (c - c_0))$$  (1)

where \(\rho_0\) is the medium density at initial condition \(T_0, c_0\), and \(\beta_T, \beta_c\) are the thermal and solute volumetric expansion coefficients, respectively.

The governing equations for laminar buoyancy convection in horizontal cavity with Soret and Dufour effects are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$  (2)

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = - \frac{1}{\rho_0 c_0} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right)$$  (3)

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = - \frac{1}{\rho_0 c_0} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - g [1 - \beta_T (T - T_0) - \beta_c (c - c_0)]$$  (4)

$$\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \kappa_{TC} \left( \frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right)$$  (5)

$$\frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = D \left( \frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} \right) + \kappa_{CT} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)$$  (6)

where \(\nu, \alpha, D\), are kinematical viscosity, thermal diffusivity, and diffusion coefficient, respectively; \(\kappa_{TC}, \kappa_{CT}\) are the diffusion-thermo (Soret) coefficient and thermodiffusion (Dufour) coefficient resulting from coupling–diffusive interaction.
The vertical walls are adiabatic and impermeable while the horizontal walls are under uniform temperature and concentration, so the boundary conditions can be given by following equations.

\[ x = 0, \quad u = v = 0, \quad \frac{\partial T}{\partial x} = 0, \quad \frac{\partial c}{\partial x} = 0 \]  
(7)

\[ x = 4L, \quad u = v = 0, \quad \frac{\partial T}{\partial x} = 0, \quad \frac{\partial c}{\partial x} = 0 \]  
(8)

\[ y = 0, \quad u = v = 0, \quad T = T_h, \quad c = c_h \]  
(9)

\[ y = L, \quad u = v = 0, \quad T = T_l, \quad c = c_l \]  
(10)

The initial condition can be expressed as

\[ t = 0, \quad u = v = 0, \quad T = T_0, \quad c = c_0 \]  
(11)

In the present study, the initial temperature and concentration are the same as those at the upper wall. To study conveniently the effects of temperature and concentration gradients on the onset of thermosolutal buoyancy convection, the following dimensionless variables are introduced:

\[ U = \frac{u}{L}, \quad V = \frac{v}{L}, \quad X = \frac{x}{L}, \quad Y = \frac{y}{L}, \quad \theta = \frac{T - T_l}{T_h - T_l}, \quad C = \frac{c - c_l}{c_h - c_l}, \quad \tau = \frac{\alpha t}{L^2}, \]

\[ P = \frac{L^2(\rho + \rho_0 g y)}{\rho_0 \alpha^2}, \quad Pr = \frac{\nu}{\alpha}, \quad Le = \frac{\alpha}{D}, \quad Ra = \frac{gL^3 \beta_T(T_h - T_l)}{\nu \alpha}, \]

\[ N_C = \frac{\beta_C(c_h - c_l)}{\beta_T(T_h - T_l)}, \quad D_f = \frac{\kappa_T c(c_h - c_l)}{\alpha(T_h - T_l)}, \quad S_r = \frac{\kappa_C T(c_h - c_l)}{D(c_h - c_l)} \]

The governing equations can be rewritten in dimensionless form as

\[ \frac{\partial U}{\partial \tau} + \frac{\partial V}{\partial Y} = 0 \]  
(12)

\[ \frac{\partial U}{\partial \tau} + U \frac{\partial U}{\partial X} + V \frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + Pr \left( \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \right) \]  
(13)

\[ \frac{\partial V}{\partial \tau} + U \frac{\partial V}{\partial X} + V \frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + Pr \left( \frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} \right) + Ra \cdot Pr(\theta + N_C C) \]  
(14)

\[ \frac{\partial \theta}{\partial \tau} + U \frac{\partial \theta}{\partial X} + V \frac{\partial \theta}{\partial Y} = \left( \frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} \right) + D_f \left( \frac{\partial^2 C}{\partial X^2} + \frac{\partial^2 C}{\partial Y^2} \right) \]  
(15)

\[ \frac{\partial C}{\partial \tau} + U \frac{\partial C}{\partial X} + V \frac{\partial C}{\partial Y} = \frac{1}{Le} \left[ \left( \frac{\partial^2 C}{\partial X^2} + \frac{\partial^2 C}{\partial Y^2} \right) + S_r \left( \frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} \right) \right] \]  
(16)
and the dimensionless boundary and initial conditions are

\begin{align}
X &= 0, \quad U = V = 0, \quad \frac{\partial \theta}{\partial X} = 0, \quad \frac{\partial C}{\partial X} = 0 \tag{17} \\
X &= 4, \quad U = V = 0, \quad \frac{\partial \theta}{\partial X} = 0, \quad \frac{\partial C}{\partial X} = 0 \tag{18} \\
Y &= 0, \quad U = V = 0, \quad \theta = 1, \quad C = 1 \tag{19} \\
Y &= 1, \quad U = V = 0, \quad \theta = 0, \quad C = 0 \tag{20} \\
\tau &= 0, \quad U = V = 0, \quad \theta = 0, \quad C = 0 \tag{21}
\end{align}

where the dimensionless parameters are the buoyancy ratio \(N_C\), Lewis number \(Le\), Soret coefficient \(Sr\), Dufour coefficient \(Df\), and Rayleigh number \(Ra\).

To characterize heat and mass transfer in buoyancy convection and diffusion, the local Nusselt number \(Nu\) and Sherwood number \(Sh\) are defined as

\begin{align}
Nu(X) &= \left. \frac{\partial \theta}{\partial Y} \right|_{Y=0} + Df \left. \frac{\partial C}{\partial Y} \right|_{Y=0} \tag{22} \\
Sh(X) &= \left. \frac{\partial C}{\partial Y} \right|_{Y=0} + Sr \left. \frac{\partial \theta}{\partial Y} \right|_{Y=0} \tag{23}
\end{align}

where the first and second terms characterize Fourier’s thermal flux and diffusion-thermo flux, respectively, in Eq. (22). In expression of Sherwood number, the first and second terms characterize Fick’s diffusion flux and thermodiffusion flux, respectively. In addition, the average Nusselt number and Sherwood number are defined as

\begin{align}
\overline{Nu} &= \frac{1}{4} \int_{0}^{4} Nu(X) \, dX \tag{24} \\
\overline{Sh} &= \frac{1}{4} \int_{0}^{4} Sh(X) \, dX \tag{25}
\end{align}

3. NUMERICAL SOLUTION

The governing equations used here are typical coupling convection–diffusion equations which can be discretized by the finite volume method [30] and solved numerically. The SIMPLE algorithm with high-precision QUICK scheme for convective and diffusive terms is employed. Meanwhile, the Euler backward second-order implicit scheme is used for the unsteady state term. The boundary conditions are merged into energy and momentum equations for the appropriate nodes using the additional source term method [30]. During the SIMPLE iteration process, some under-relaxation is necessary; the relaxation factor used here is \(0.4 \sim 0.5\).

In the numerical simulation, the effects of grid size and time step on flow characteristics were examined. Considering simulated accuracy and computing cost, a
uniform grid of 180 × 80 (in the x- and y-directions) points and time step of 0.002 are generally used. To improve equation convergence under conditions of higher buoyancy, the block-correction technique [31, 32] is applied to solve the momentum equations. In addition, a nonuniform grid is used in cases with high Rayleigh number (i.e., fine grids near the walls and coarse grids distant from the walls). Considering the convergence of numerical results, the criterion of the one-time step is

$$\sum_{ij} \left| \phi_{ij}^n - \phi_{ij}^{n-1} \right| < 10^6$$

(26)

where $\phi$ is the generic variable that can be $U$, $V$, $\theta$, or $C$, and the superscript $n$ indicates the iteration number within one time step. The subscript sequence $(i, j)$ represents the grid node.

4. RESULTS AND DISCUSSION

To demonstrate the validity of the simulation code for thermosolutal convection in a horizontal cavity considering coupling–diffusive interaction, the computer program developed is first applied to simulate natural convection in a square cavity, which was studied by Barakos [33]. The dimensionless parameters in Eqs. (12)–(16), $N_C$, $S_r$, and $D_f$ are all set to zero, Lewis number is 1, $Pr$ is 0.71, and the concentration of the entire domain is always zero. Table 1 shows a comparison of results obtained in the present work and those of Barakos [33]. It will be seen that the average Nusselt number in the present work and Barakos [33] are in good agreement with each other, even at higher $Ra$. The maximum relative deviation is less than 1% with $Ra = 10^6$ and it is within computational uncertainty.

The second case for code validation is thermosolutal convection and diffusion without coupling–diffusive interaction in a square cavity under varying $Ra$ and $N_C$, which was investigated by Béghein et al. [10]. The dimensionless parameters $S_r$ and $D_f$ are both zero, $Le$ is 1, and $Pr$ is 0.71. The range of buoyancy ratio is $-5$ to $-0.1$ (i.e., the direction of thermal buoyancy is opposite to that of solutal buoyancy). As can be seen from Figure 2, agreement between numerical and Béghein solutions [10] for thermosolutal convection and diffusion without coupling–diffusive interaction in a square cavity is very good under all conditions. Meanwhile, Figure 2 shows that there is a turning point for average Nusselt number near $-1$ of the buoyancy ratio.

Numerical simulation is then performed for the coupling–diffusive model of air to investigate the characteristics of thermosolutal convection and diffusion in a horizontal cavity. Prandtl and Lewis numbers are taken as 0.71 and 1.641, respectively. Figure 3 illustrates three typical flow patterns in a horizontal cavity under

<table>
<thead>
<tr>
<th>$Ra$</th>
<th>Barakos and Mitsoulis [33]</th>
<th>Present study</th>
<th>Deviation (%)</th>
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<td>$10^3$</td>
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<td>$10^6$</td>
<td>8.806</td>
<td>8.891</td>
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varying Rayleigh number. Four-vortex flow patterns are obtained when $Ra = 10^4$, as shown in Figure 3a because thermosolutal buoyancy results in rising hot airflow near the left and right wall, and this is extruded towards the middle of the upper wall and collides with rising airflow at the middle of the wall which then moves along the upper wall. As Ra increases, fluid flow shows six vortices (seen in Figure 3b) and

![Flow patterns in a horizontal cavity under different Rayleigh numbers ($N_C = -0.2$, $Sr = D_f = 0.5$).](image)

**Figure 2.** Comparison of Béghein and numerical solutions for thermosolutal buoyancy convection without coupling–diffusive interaction in a square cavity.

**Figure 3.** Flow patterns in a horizontal cavity under different Rayleigh numbers ($N_C = -0.2$, $Sr = D_f = 0.5$).
is then converted to four further vortices (shown in Figure 3c) due to higher thermal and solutal buoyancy induced by increasing temperature difference between the upper and lower walls with increasing Ra.

Figure 4 shows the effect of Rayleigh number on thermosolutal buoyancy convection. It demonstrates that both $\overline{Nu}$ and $\overline{Sh}$ are initially constant and then increase with $Ra$, but there is an inflexion point beyond which $\overline{Nu}$ and $\overline{Sh}$ are no longer

![Figure 4. Effect of Rayleigh number on thermosolutal convection ($N_C = -0.2$).](image)
constant. Through fluid flow investigation, it is found that the velocity of the system is almost zero and conduction plays a predominant role because thermosolutal buoyancy is minimal while Rayleigh number is lower than the inflexion point; convective heat transfer and mass diffusion are obvious due to the greater thermosolutal buoyancy resulting from large temperature and concentration differences under high $Ra$.

Figure 5. Effect of buoyancy ratio on thermosolutal convection ($S_r = D_r = 0.2$).
In addition, it can be seen that $\overline{Nu}$ and $\overline{Sh}$ rise congruously with $Sr$ and $Df$ as the coupling–diffusive interaction builds. The inflexion point of fluid flow transition moves towards higher Rayleigh numbers as the coupling–diffusive interaction increases.

Figure 5 shows the effect of buoyancy ratio on heat and mass transfer of thermosolutal convection in a horizontal cavity. Both $\overline{Nu}$ and $\overline{Sh}$ remain constant under all Rayleigh numbers when buoyancy ratio $N_C$ is less than $-1$. Furthermore, numerical investigation of flow field was conducted and it is found that velocity is almost zero throughout the entire cavity. In other words, the system shows conductive characteristics and heat and mass transfer from bottom (high concentration) to top (low concentration) of the horizontal cavity is mainly driven by concentration difference,

**Figure 6.** Soret effect on thermosolutal convection ($N_C = -0.2, D_f = 0.1$).
because solutal buoyancy is greater than thermal buoyancy. As $N_C$ increases, there are two inflexion points on the heat and mass transfer characteristic curve as shown in Figure 5. The first, conduction–convection inflexion, is identical to the inflexion point in Figures 4a, b where the fluid field changes to thermosolutal buoyancy convection from conduction-dominated. Meanwhile, the rising curve becomes steeper and conduction–convection inflexion moves towards a lower buoyancy ratio as $Ra$ increases. However, the rising curve becomes relatively flat near the second inflexion point where the fluid field transforms from four to six vortices, as shown in Figure 3b; furthermore this transformation occurs earlier under higher Rayleigh numbers.

Figure 6 illustrates the Soret effect on thermosolutal buoyancy convection. The results show that there is almost no influence of Soret coefficient on heat transfer,

Figure 7. Dufour effect on thermosolutal convection ($N_C = -0.2, S_r = 0.1$).
except at high $Ra$. As seen from Figure 6a, average Nusselt number decreases only slightly as Soret coefficient increases at $Ra = 10^5$, but the change is negligible. Consequently, heat transfer in thermosolutal convection is generally not relevant to Soret effect because the weak Dufour effect ($Df = 0.1$) on heat transfer is constant. Unlike $Nu$ and $Sh$ which grow linearly with Soret coefficient, the linear line is steeper under higher $Ra$ as shown in Figure 6b. Briefly, mass transfer and diffusion driven by concentration difference and Soret effect become more intense with increasing Soret coefficient owing to the increasing impact of thermal buoyancy on concentration as $Sr$ increases.

Figure 7 shows the Dufour effect on thermosolutal convection. It can be seen that average Nusselt number has a significant linear correlation with Dufour coefficient in Figure 7a, and the slope of the curve becomes steeper as $Ra$ increases. The main reason is that not only temperature difference, but also Dufour effect due to concentration difference, enhances heat transfer in thermosolutal convection. Moreover, the effect is more intense under high $Ra$ because fluid velocity is higher in the four or six vortexes, as shown in Figure 3. As shown in Figure 7b, average Sherwood number remains constant at $Ra = 10^3$ due to conduction-dominated fluid flow, while $Sh$ increases insignificantly at $Ra = 10^4$ and is exacerbated at high $Ra$ because coupling–diffusive interaction occurs. In other words, mass diffusion is influenced simultaneously by concentration difference and Soret effect induced by temperature difference, the latter being under the Dufour effect.

5. CONCLUSIONS

Coupling–diffusive effects on thermosolutal buoyancy convection with Soret and Dufour effects in a horizontal cavity were modeled by a coupling–diffusive model. The model was validated by comparison to heat transfer with thermosolutal convective and diffusive processes in a square cavity. Systematic numerical investigation of the coupling–diffusive effects on flow patterns, heat transfer, and mass diffusion are presented for various values of $Ra$, $NC$, $Df$, and $Sr$.

Three typical flow patterns are dominated mainly by thermal buoyancy and solutal buoyancy in a horizontal cavity with coupling–diffusion interaction, and there are inflexion points of flow pattern transform with increased Rayleigh number or buoyancy ratio. Parametric study demonstrates that heat and mass transfer of thermosolutal convection are enhanced with increased Rayleigh number or buoyancy ratio, and that coupling–diffusive interaction has a significant linear effect on heat transfer and mass diffusion in a horizontal cavity, especially under high $Ra$.

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