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Numerical study of double diffusive mixed convection around a heated cylinder in an enclosure

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ABSTRACT

This article reports numerical solution of the double diffusive mixed convection phenomena around a heated cylinder in an enclosure. The heated cylinder is located at the center of the enclosure with high temperature and concentration. The inlet flow with low temperature and concentration is located at the lower-left wall of the enclosure and the exit is at the upper-right wall. Other walls are assumed to be adiabatic. The influences of Lewis number *Le*, buoyancy ratio *Br* and Richardson number *Ri* on the double diffusive mixed convection are investigated while the Prandtl and Grashof numbers are kept at 0.7 and 1.4×10^4, respectively. Streamlines, isotherms, isoconcentrations, and the local and average Nusselt number and Sherwood number under different parameters are reported to characterize the mixed convection in an enclosure.

1. Introduction

Double diffusive convection flow in an enclosure has wide applications in industry and infrastructure, such as space heating, pollutant removing, thermal comfort, drying technologies, crystal growth, impurities migration, and metal solidification processes [1–5]. Alleborn et al. [6] numerically investigated the steady two-dimensional flow accompanied by heat and mass transports in a shallow lid-driven cavity with a moving heated lid and a moving cooled lid. Kalla el al. [7] adopted Darcy model with the Boussinesq approximation to study the double-diffusive natural convection in a shallow porous cavity. Chamkha and Al-Naser [8] studied the unsteady laminar double-diffusive convective flow in an inclined rectangular enclosure filled with a uniform porous medium. An oscillatory flow behavior within the enclosure was predicted and decay in the oscillatory behavior was also observed. Costa [9] investigated double-diffusive natural convections in parallelogrammic enclosures. Emphasis was given to the situation when the porous media in the enclosure were saturated with moist air. The same author [10] also pointed out that the combinations of the aspect ratio and inclination angle could lead to considerably high heat and mass flows through the enclosure.

Brown and Lai [11] numerically examined the combined heat and mass transfer from a horizontal channel with an open cavity heated from below. The correlations for the entire convection regime were proposed. Al-Amiri et al. [12] carried out a numerical study of steady mixed convection in a square lid-driven cavity under the combined buoyancy effects of thermal and mass diffusion for $4 \times 10^{-4} \le Ri \le 10$, $1 \le Le \le 50$, and $-100 \le Br \le 100$. Jeng et al. [13] performed the experimental and numerical studies of the transient natural convection flow and transport process due to mass transfer in the enclosures inclined at different angles. The Rayleigh number ranged from 1.126×10^8 to 1.157×10^{11} and the angle of inclination varied from 30 to 90°; the aspects ratio of the enclosure was changed from 0.6 to 1. Mahapatra et al. [14] studied the influence of buoyancy ratio on double-diffusive natural convection in a lid-driven square cavity with uniform and non-uniform thermal and concentration boundary conditions at the bottom and left vertical walls.

Teamah [15] carried out a numerical investigation to the double-diffusive laminar mixed convection in a two-dimensional horizontal annulus. The study covered a wide range of parameters for $10^2 \le Ra_T \le 10^6$, $0.1 \le Le \le 10$ and $-20 \le Br \le 20$. Later, the same author studied the double-diffusive convective flow in a rectangular enclosure with the insulated and impermeable upper and lower surfaces for $10^3 \le Ra_T \le 10^6$, $0 \le Ha \le 200$, $-50 \le \varphi \le 25$ and $-10 \le Br \le 10$ in the presences of magnetic field and heat source [16]. Teamah et al. [17] performed the numerical study to the inclined rectangular enclosure for the similar cases. Teamah and El-

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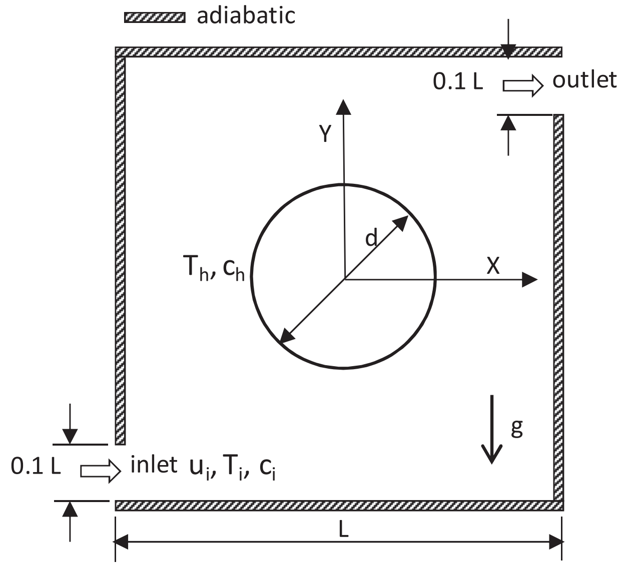

Fig. 1. Schematic diagram of the physical model.

Maghlany [18] studied the double-diffusive mixed convective flow in a rectangular enclosure with insulated moving lid and the dimensional number of $0.1 \le Le \le 50$, $0.01 \le Ri \le 10$ and $-10 \le Br \le 10$. Chen et al. [19] employed a Lattice Boltzmann model to investigate double diffusion induced convection at high Rayleigh number with the ratio of buoyancy forces $0.8 \le Br \le 1.3$, the aspect ratio $0.5 \le A \le 2$ and the radius ratio $1.5 \le K \le 3$.

Sun et al. [20] presented an extension of a slightly compressible flow model to double-diffusive convection of binary mixtures of ideal gases in a cavity. Variable density effects on thermosolutal natural convection in a vertical cavity filled with a binary mixture of ideal gases were numerically investigated. Ching et al. [21] used finite element simulation to study the impact of buoyancy ratio *Br*, Richardson number *Ri* and the direction of the sliding wall motion on the heat and mass transfer in a right triangular enclosure at fixed Lewis Number. Hasanuzzaman et al. [22] investigated effects of Lewis number on heat and mass transfer for the same case. Rahman et al. [23] analyzed the effects of buoyancy ratio and Lewis number on heat and mass transfer in a triangular cavity with zig-zag shaped bottom wall for different buoyancy ratios ($10 \le Br \le 10$), Lewis numbers ($0.1 \le Le \le 20$), and thermal Rayleigh numbers ($10^4 \le Ra_T \le 10^6$). Al-Farhany and Turan [24] performed the numerical study of two-dimensional double-diffusive natural convective heat and mass transfer in an inclined rectangular porous medium. Effects of different non-dimensional parameters, including aspect ratio ($2 \le A \le 5$), angle of inclination of the cavity ($0 \le \phi \le 85$), Lewis number ($0.1 \le Le \le 10$), and the buoyancy ratio ($-5 \le Br \le 5$), on the double-diffusive natural convection were studied. Nikbakhti and Rahimi [25] numerically studied double-diffusive natural convection in a rectangular cavity with partially thermally active side walls filled with air.

For special applications of the double diffusive mixed convection in air ventilation and pollutant control, Liu et al. [26] reported a numerical study on removal of two contaminants from a three-dimensional enclosure with one inlet, one exhausting port, and one returning port. The influences of inlet velocity, fresh air ratio, recirculating air filtered removal efficiency and contaminant property were investigated. Deng et al. [27] investigated the characteristics of the airflow and heat/contaminant transport structures in the indoor air environment by means of a convection transport visualization technique. Xamán et al. [28] analyzed the effect of a contaminant source (CO_2) on the air quality in a ventilated room. Different outlet gap positions were proposed to identify the best performance from a thermal comfort point of view and air quality with the exception of configurations with a contaminant source of 1000 ppm. Correlations for the average Nusselt and Sherwood numbers were proposed. Liu et al. [29] numerically modeled the thermal transport and transient dispersion of pollutants emitted from two discrete strips within the displacement ventilation enclosure with Reynolds number of $2 \times 10^3 \le Re \le 10^4$ and Grashof number of $10^6 \le Gr \le 10^{10}$. While most studies are focused on two-dimensional scenarios, Chen et al. [30] investigated the double-diffusive buoyancy convection in a three-dimensional square cuboid. They adopted the direction numerical simulation and found typical pitchfork bifurcation when each parameter varied and suggested that a 2D model significantly over-predicted the heat and mass in some parameter ranges.

Besides the lid-driven, inlet supply or sidewall-driven motion, most researches on double-diffusive convection were focused on natural convection in enclosures. No studies are performed on the mixed double-diffusive convection in an enclosure with heated cylinder, which is a typical model for the pollutant removing, smoke control in infrastructures and industrial drying technologies. The double diffusive mixed convection characteristics in an enclosure is influenced by a wide range of pertinent controlling parameters, including Prandtl number *Pr*, Grashof number *Gr*, Richardson number *Ri*, Lewis number *Le*, buoyancy ratio *Br*, Nusselt number *Nu* and Sherwood number *Sh*.

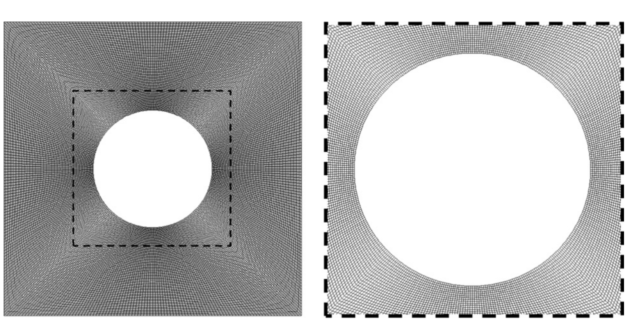

Fig. 2. Numerical grid scheme.

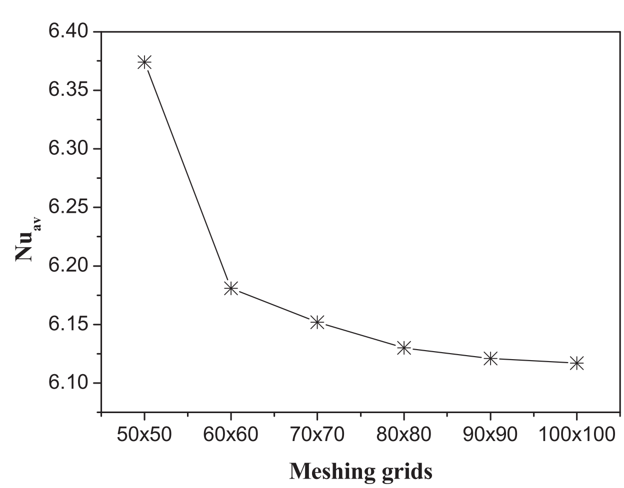

Fig. 3. Grid independency check for the average Nusselt number around the heated cylinder at $Ri = 0.01$, $Br = 10.0$ and $Le = 1.0$.