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International Journal of Heat and Mass Transfer 51 (2008) 383–388
International Journal of HEAT and MASS TRANSFER
www.elsevier.com/locate/ijhmt

Technical Note

Numerical analysis of double-diffusive convection in a porous enclosure due to opposing heat and mass fluxes on the vertical walls – Why does peculiar oscillation occur?

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Received 10 November 2006; received in revised form 3 August 2007
Available online 1 November 2007

Abstract

Peculiar oscillating convection is observed when two-dimensional double-diffusive convection in porous medium is analysed numerically. The top and bottom walls of an enclosure are insulated, and constant and opposing heat and mass fluxes are prescribed on the vertical walls. The peculiar oscillations are of three types: (1) Chaotic oscillations wherein the main flow is due to temperature; however, the convection due to concentration is strong enough to generate this peculiar oscillation. (2) The 'sudden steady state case' caused by the shifts from thermally-driven to concentration-driven forces. (3) The 're-oscillation case' caused by the convection pattern changes from centrosymmetric to non-centrosymmetric.

Keywords: Double diffusion; Porous medium; Buoyancy ratio; Numerical simulation; Peculiar oscillation

1. Introduction

Double-diffusive convection in porous medium, which occurs because of temperature and concentration differences, is observed in many disciplines, for example, electrochemistry, geophysics, etc. [1–3]. Because heat and mass transfers in a membrane influence the reaction [4], it is important to understand the double-diffusive convection in porous media in detail. Various authors have theoretically and numerically studied the double-diffusive convection in a fluid-saturated porous enclosure due to the opposing heat and mass fluxes on vertical walls [5–12]. In these studies, the numerical calculations yielded oscillatory solutions [9,10]. In the former paper [9], we performed calculations only when the aspect ratio was 5. Furthermore, it has been observed that the oscillation pattern of Nusselt number *Nu* changes abruptly with time. In this paper, we have performed calculations in order to clarify why such peculiar oscillations occur. By analysing the double-diffusive convection pattern, we intend to elucidate the physical mechanism responsible for the occurrence of such oscillations. In conclusion, three distinct kinds of peculiar oscillations can be observed, and accordingly, the peculiar oscillations are classified into three types.

2. Problem statements

We consider a two-dimensional vertical enclosure filled with a homogeneous, fluid-saturated porous medium of aspect ratio A. The top and bottom walls are insulated. Constant heat flux Λ_T and mass flux Λ_c are prescribed through the vertical walls. The governing equations are as follows: equation of momentum conservation in the Darcy regime with the Boussinesq approximation, equation of continuity and equations for the mass and thermal

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doi:10.1016/j.ijheatmasstransfer.2007.09.002

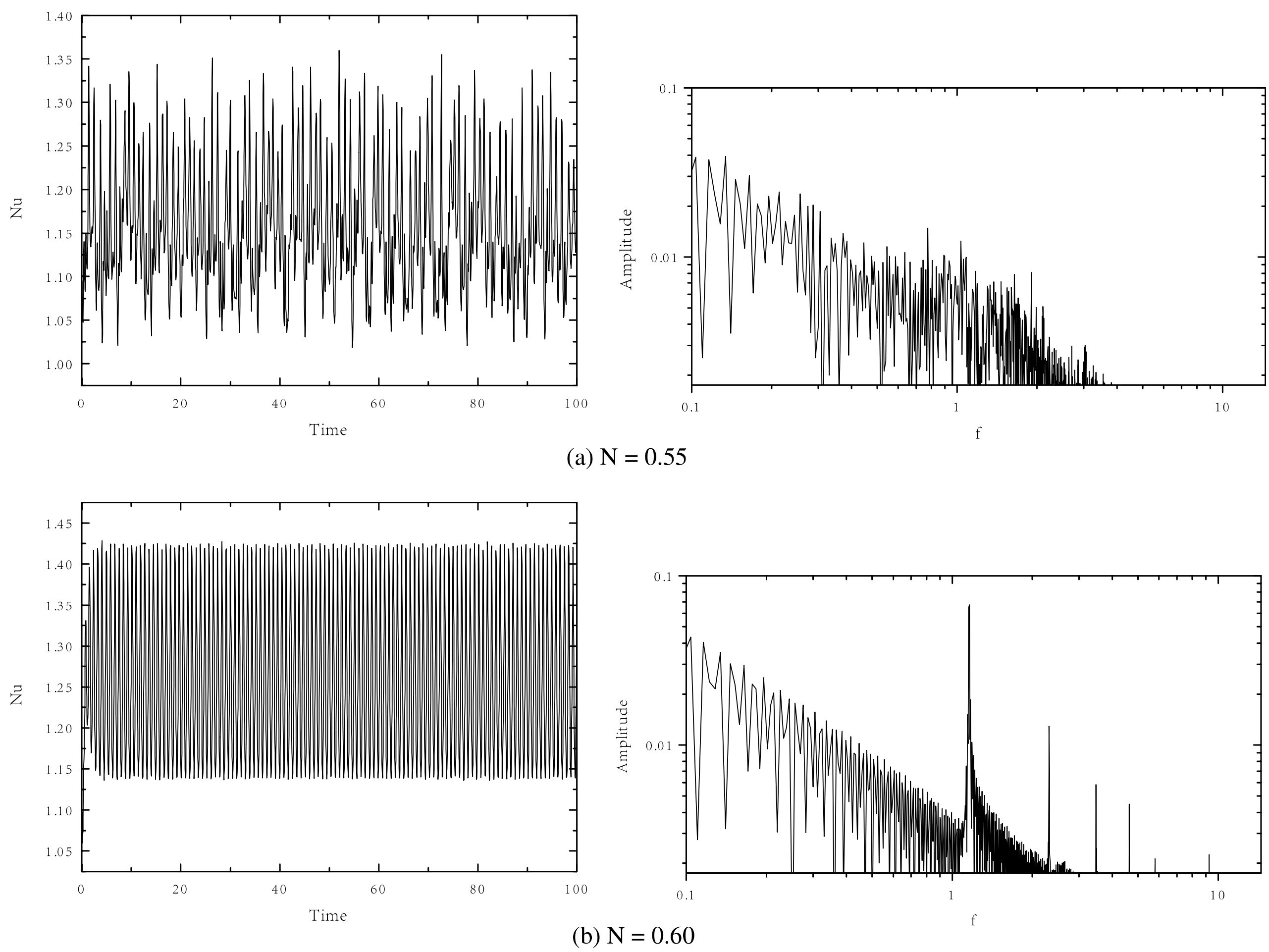

Fig. 1. FFT of the time-dependence of Nusselt number when $R = 100$, $Le = 20$ and $A = 5$.

energy conservation. The velocities, temperature and concentration are zero at the initial condition. The buoyancy ratio is defined by

$$N = \frac{\alpha \Lambda_T}{\beta \Lambda_c}, \tag{1}$$

where α is coefficient of thermal expansion and β is coefficient of concentration expansion.

Governing equations are solved numerically with the boundary and initial conditions by the finite difference method. No grid point is set on the physical boundaries ($|x| = 1$ and $|y| = A$). The first and end grid points are placed at a distance of half a grid space away from the boundaries. The boundary conditions at the walls are applied to these points. The numerical scheme used here is second-order accurate in space and first-order accurate in time. The matrices are solved under the given boundary conditions by the conjugate gradient method. For further details regarding this method, refer to Ref. [8].

In the previous calculations [9], the numerical grids of 62×302 were sufficient because we considered only the simple oscillation case. However, it is necessary to use a smaller mesh in order to study the peculiar oscillation problem. We have attempted to calculate when the grid size exceeds 62×302. The oscillation patterns of Nu are similar when the grid size exceeds 102×502. Therefore, we can arrive at a solution of sufficient accuracy in the present calculation if we use grids greater than 102×502.

In the present study, we performed calculations for the following cases: the Rayleigh–Darcy number $R = 50$, 100 and 200; the Lewis number $Le = 2$, 5, 10, 20 and 50; and the aspect ratio $A = 2.5$ and 5.

3. Results and discussion

3.1. Chaotic oscillation case

N_{min} is defined as the minimum value of the buoyancy ratio that generates oscillation. In our previous study [9], we observed that the oscillation of Nu was very complex near N_{min}; however, the reason for this oscillation pattern was not clear. Fig. 1 shows the oscillations of Nu and the corresponding FFT when $R = 100$, $Le = 20$ and $A = 5$. In this case, $N_{min} = 0.53$. As shown in Fig. 1a, Nu oscillates randomly and a clear peak is not observed in the FFT. From these figures, chaotic oscillation can be observed when $N = 0.55$. In the previous research [9], we were unable to determine whether the oscillation of Nu was cha-