ELSEVIER

Desalination 183 (2005) 173–178

DESALINATION

www.elsevier.com/locate/desal

Natural convection effects in solar stills

Ahmed Omri, Jamel Orfi*, Sassi Ben Nasrallah

Laboratoire d'Etude des Systèmes Thermiques et Energétiques, Ecole Nationale d'Ingénieurs de Monastir, Tunisie
email: ahmed.omri@ipeim.rnu.tn, jamel.orfi@fsm.rnu.tn

Received 28 March 2005; accepted 15 April 2005

Abstract

This paper deals with a numerical simulation of natural convection flows in a triangular cavity submitted to a uniform heat flux using the Control Volume Finite Element Method.

The aim of the study is to examine the thermal exchange by natural convection and effects of buoyancy forces on flow structure. The study provides useful informations on the flow structure sensitivity to the governing parameters, the Rayleigh number and the tilt angle, on the thermal exchange. In a basin still receiving a uniform heat flux, the results show that the bottom is not isotherm and the flow structure is sensitive to the cover tilt angle. Many recirculation zones can occur in the core of the cavity and the heat transfer is dependent on the flow structure. The results of this study can provide informations for the enhancement of the design of the energy systems such as solar water distillers and air conditioning systems.

The physical problem concerns a two-dimensional incompressible fluid flow generated inside a triangular enclosure with isotherm upper walls and heated bottom. The hydrodynamic and thermal fields, the local Nusselt number, the temperature profile at the bottom and at the center of the cavity are investigated for a large range of Rayleigh number. The effect of the upper sides inclination is examined for the particular value of $Ra=10^5$.

Keywords: Rayleigh number; Nusselt number; Natural convection; Heat transfer

1. Introduction

Understanding the hydrodynamic and heat transfer processes is important for effective design of solar distiller. The fresh water production is dependent on various factors. The distillation rate is governed, among others, by the cover tilt [1], the cover transparency [2] and the plate absorption [3,4]. The productivity was found to increase by forcing air inside the still [5].

Inspection of the literature reveals that most of the research emphasizes experimental investigations of the temperature field in triangular cavities and measurements of the hourly production of solar stills. Therefore,

*Corresponding author.

Presented at the Conference on Desalination and the Environment, Santa Margherita, Italy, 22–26 May 2005. European Desalination Society.

0011-9164/05/$– See front matter

numerical study can be an important help for system conception and experimental conditions. In this paper, attention is focused on the study of the natural convection heat transfer in a two dimensional triangular cavity with two isothermal sidewalls and a bottom submitted to a uniform heat flux.

2. Numerical method

Using the secondary formulation (Ψ–ω), governing equations are as follows, respectively equation of Poisson for the stream function, transport equations for vorticity and energy equation:

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} = -\omega \tag{1}$$

$$U\frac{\partial \omega}{\partial x} + V\frac{\partial \omega}{\partial y} = \left[\frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2}\right] + \frac{Ra\partial T}{Pr\partial x} \tag{2}$$

$$U\frac{\partial T}{\partial x} + V\frac{\partial T}{\partial y} = \frac{1}{Pr}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] \tag{3}$$

The velocity field is deducted from equation (4) while using for derivatives of Ψ, the centred differences of second order.

$$U = -\frac{\partial \Psi}{\partial Y}, V = \frac{\partial \Psi}{\partial x} \tag{4}$$

A Control Volume Finite Elements Method [8–10] is used in this computation. The domain of interest is divided in triangular elements and a polygonal volume is constructed around each nod by joining the element centre with the middle of sides. The set of governing equations is integrated over the Control Volume with use of an exponential interpolation in the mean flow direction and a linear interpolation in the transversal direction inside the finite element. The algebraic equations are then solved by the Gauss-Seidel Method.

The object of this paper is to report results relevant on steady natural convection in a triangular cavity for the range $10^4 < Ra < 10^6$. This range of Rayleigh number characterizes solar collector spaces of triangular shape [7]. The angle between the cover and the bottom takes various values. The fluid considered in this study is the air.

This study is a first part of a research in which the present results will be completed by mass transfer analysis adding the forced convection phenomenon by injection of hot air. Evidently, the proposed configuration has applications in solar collectors [6].

3. Results and discussion

3.1. Rayleigh number effect

Fig. 1 presents the streamline patterns for particular cover tilt angle of 60°. One can see

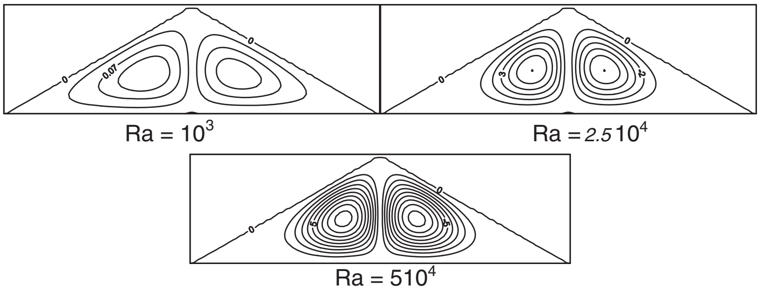

Fig. 1. Streamlines for $Ra = 10^3$; 2.510^4; $5\ 10^4$.

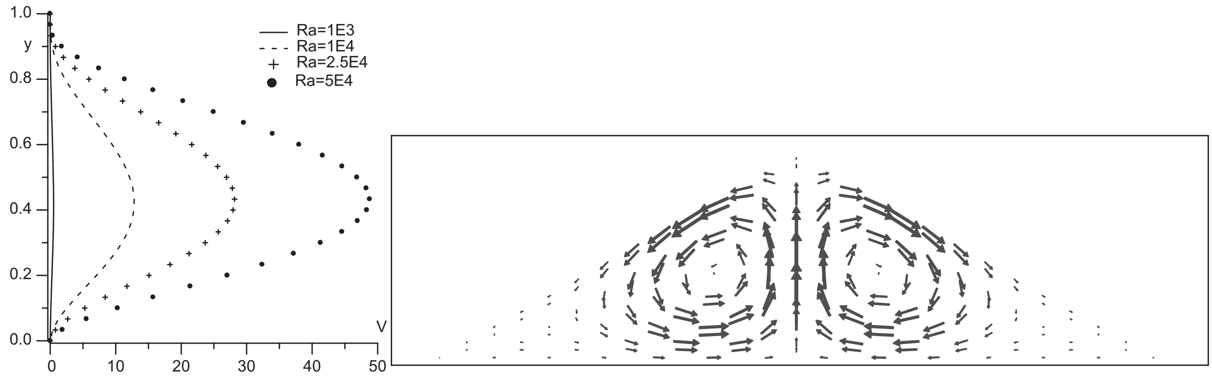

Fig. 2. a) Vertical velocity component profile. , Ra = 1E3; - - - Ra = 1E4; +, Ra = 2.5E4; •, Ra = 5E4, b) Velocity vector pattern.

that two recirculation cells grow in size by increasing the Rayleigh number. The left cell evolves in the trigonometric sense and the other cell evolves in the clockwise sense. The streamlines become tight at the mid plane indicating that the warmed fluid is accelerated well when buoyancy effects are important.

This is demonstrated by Fig. 2(a) giving the vertical velocity component profile and showing that the fluid is more accelerated at high Ra values. Fig. 2(b) shows that the fluid is pushed upward in the central part of the cavity.

As shown in Table 1, the maximum of the streamline function increases with Ra values.

As shown in the Fig. 3, the flow loses the symmetrical structure for higher Ra values, and the dynamic field becomes muticellular.

Table 1
Stream line function

Ra	1000	5000	12000	25000	50000
Ψ_{max}	0.16	1.2	3.5	6	9

3.2 Thermal field

Fig. 4 present the temperature profile along the bottom (Fig. 4a) and the temperature profile at the middle (Fig. 4b). One can see that the middle of the plate is more warmed. In this region, the temperature decreases with Rayleigh number values but it rests highest at the plate. However, the recirculation zones enlarged by buoyancy forces mixes well the

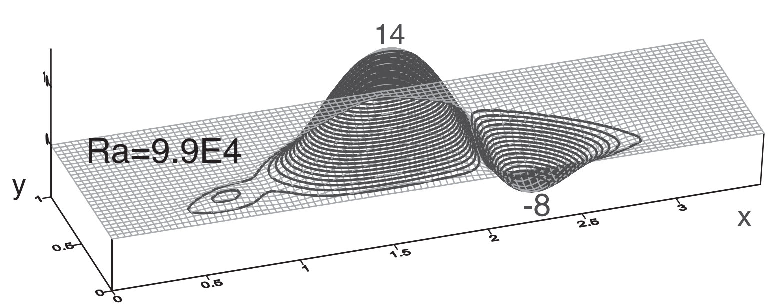

Fig. 3. Dynamic field for $Ra = 9.910^4$.

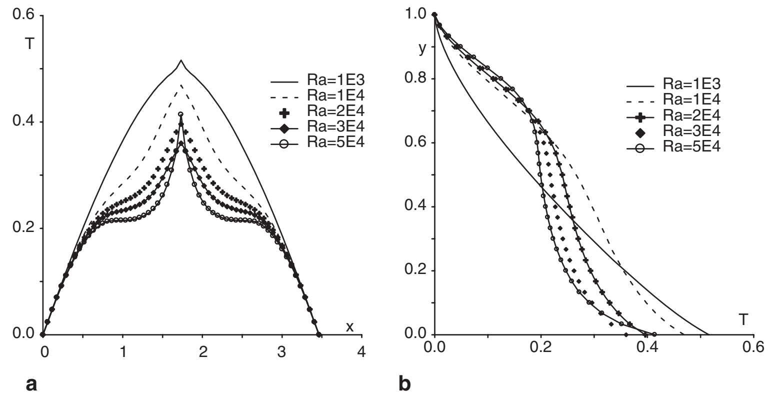

Fig. 4. a) Temperature profile at the bottom. , Ra = 1E3; - - - Ra = 1E4; +, Ra = 2E4; , Ra = 3E4; , Ra = 5E4, b) Temperature profile at the middle. , Ra = 1E3; - - - Ra = 1E4; , Ra = 2E4; , Ra = 3E4; , Ra = 5E4.

cold fluid and the arisen fluid from the bottom. The plate loses more energy. The Nusselt number admits a minimum at the bottom center. This minimum increases by increasing Ra (Fig. 5). This is agreed with thermal field structures illustrated by Fig. 6.

3.3. Cover tilt angle

Fig. 7 shows streamline patterns for the same height and for two different cover tilt angle values. One can see that widening the cavity base multiplies the number of the recirculation cells. The hot fluid, raised from the bottom, mixes well with the cold fluid and stagnation zones are established at the whole core of the enclosure. When the cavity base is less wide, only two recirculation zones occur far from the upper summit.

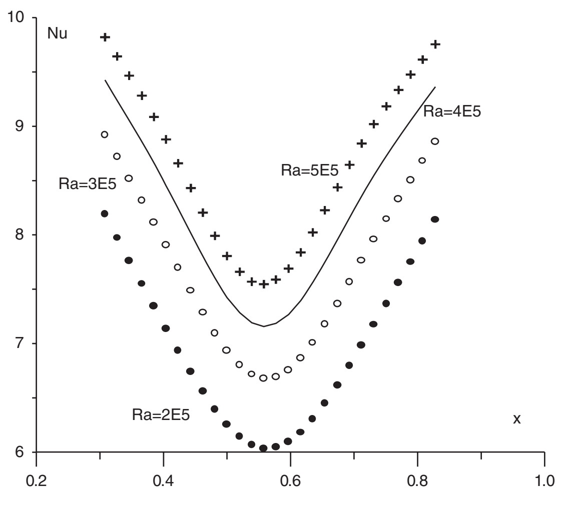

Fig. 5. Distribution of the Nusselt number on the bottom of the enclosure.

Fig. 8 presents isotherms for the particular angles of 25°. The cells multiplicity homogenizes the thermal field warming well the core of the cavity. Obviously, the thermal field is sensitive to the fluid structure change. The heat transfer is enhanced in large cavities. As illustrated in Fig. 9(a) the average Nusselt number is less important at the high cover tilt angle values. Effectively, when the upper summit is far from the heated bottom, the greater part of the cavity stays cold.

Fig. 9(b) presents the temperature evolution at the middle of the plate at various shapes. A maximum is observed for a particular cover tilt angle of 35°. Indeed, increasing the cavity base improves the thermal energy collection but at once the cavity size grows and the fluid volume becomes more important. Two antagonist effects occur in the enclosure. This can justify the critical shape corresponding to an optimal heating

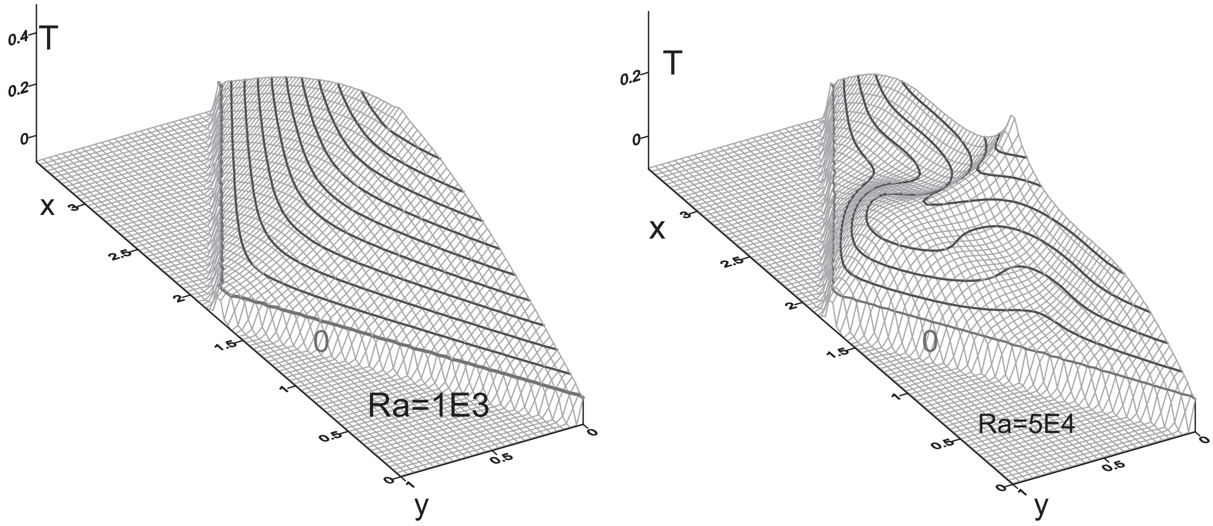

Fig. 6. Thermal field for $Ra = 1E3$ and $Ra = 5E4$.

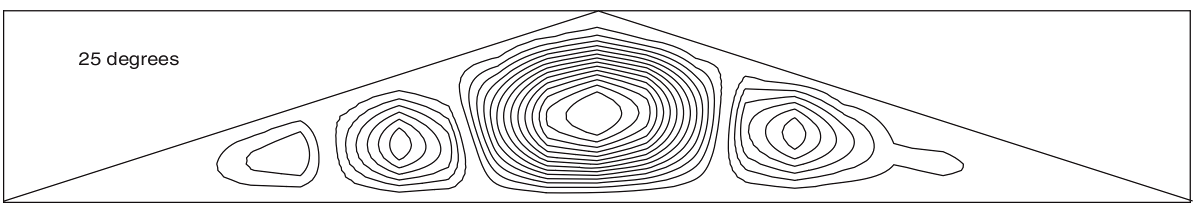

Fig. 7. Cellular multiplication structure in wide cavity.

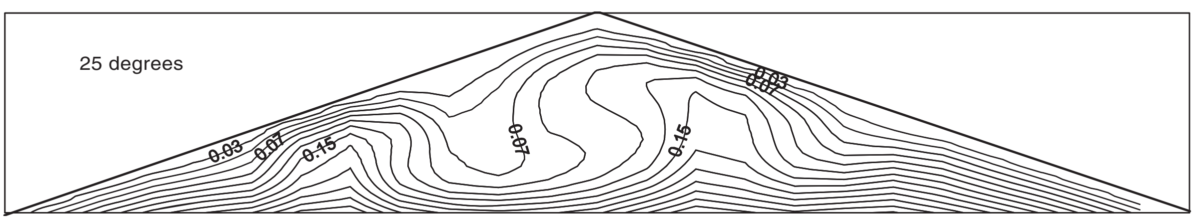

Fig. 8. Thermal field in a wide cavity.

at the mid plate. It can be noted here that Bilal et al. [3], examining the low angle values, has obtained a maximum of the fresh water production at an angle 35°.

4. Conclusion

A numerical investigation of laminar natural convective in a triangular cavity with isothermal upper sidewalls and receiving a uniform continuous heat flux at the bottom has been considered in this paper. The study showed that the flow structure and the heat transfer are sensitive to the cavity shape and to the Rayleigh number. An optimum tilt angle was determined corresponding to a minimum of the Nusselt number and for a

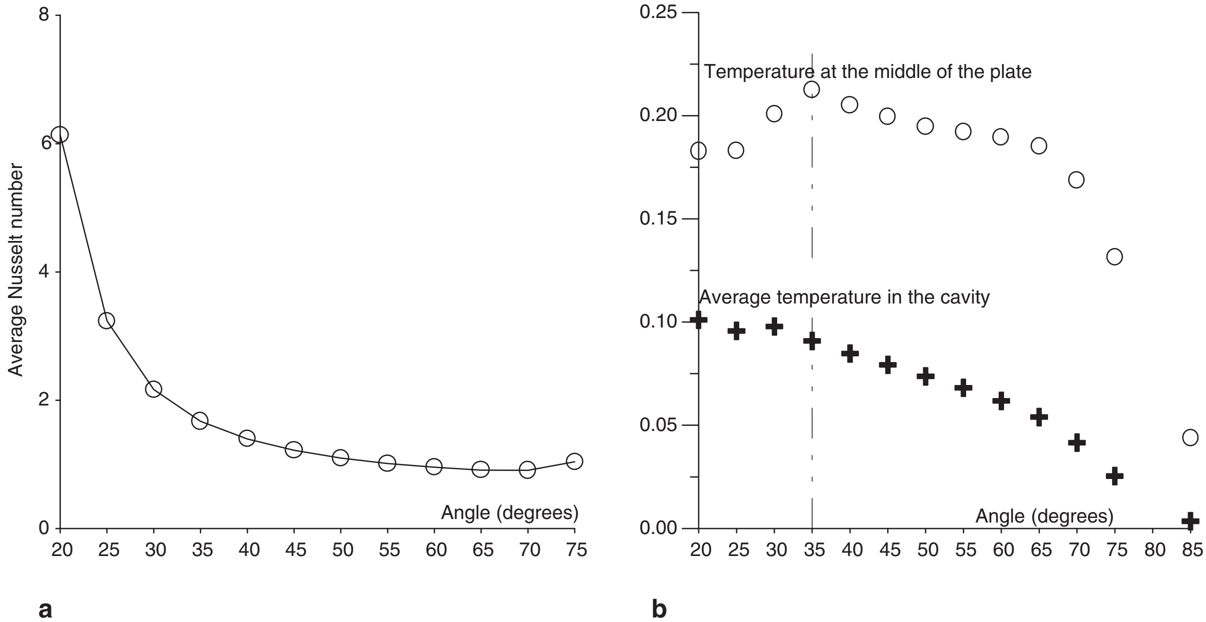

Fig. 9. Cover tilt angle effect.

maximum of the temperature at the bottom center. Many recirculation zones can occur making homogeneous the thermal field in the core of the cavity.

References

[1] A.A. Bilal, M.S. Mohsen and N. Waleed, Experimental study of basin solar still under local climate conditions. Energ. Convers. Manage., 41 (2000) (1999) 883–890.

[2] A. Ghneyem and A. Ileri, Software to analyze solar still and an experimental study on the effects of the cover. Desalination, 114 (1) (1997) 37–44.

[3] A.K. Rjvanshi, Effect of various Dyes on solar Distillation. Sol. Energy, 27 (1) (1981) 299–306.

[4] G.N. Tiwari in: Recent advances in solar distillation; R. Kamal, K.P. Maheshwari and R.L. Sawlney eds Wiley Eastern, New Delhi, 1992, Chap. 2.

[5] H. Ali, Experimental study on air motion effect inside the solar still on still performance. Energ. Convers. Manage., 32 (1991) 67–70.

[6] M.T. Chaibi, M.J. Safi and M. Hsairi, Performance analysis of a solar desalting unit in south Tunisia. Desalination, 82 (1991) 197–205.

[7] R.D. Flack, T.T. Konopnicki and. J.H. Rooke, Measurement natural convective heat transfer triangular enclosure, ASME J. Heat Transfer, 101 (4) (1979) 648–654.

[8] B.R. Baliga, A control-Volume based finite element method for convective heat and mass transfer, PhD Thesis, University of Minnesota, Minneapolis, U.S.A. 1978.

[9] B.R. Baliga and S.V. Patankar, A control Volume finite-element method for tow-dimensional fluid flow and heat transfer. Numer. Heat Transfer, 6 (1983) 245–261.

[10] A. Omri, Etude de la convection mixte à travers une cavité par la méthode des Volumes de contrôle à base d'éléments finis. Thèse de Doctorat, Faculté des Sciences de Tunis, 2000.