INTERNATIONAL CONFERENCE ON ADVANCES IN MECHANICAL ENGINEERING

PROCEEDINGS BOOK

ISTANBUL, 2015

OPENING SPEECH

Dear Our Rector, Dean, Department Head and Audience,

It gives me great pleasure to extend to you all a very warm welcome on behalf of the Organizing Committee. It is an opportune time to have collaboration with other researchers and discuss problems of mutual interest with participants from the World now.

First of all, we need to thank our rector again for his support to this organization. There were over 500 accepted abstracts and 22 invited speakers as they can be seen from our conference website. Unfortunately, we have got 280 submitted full papers and posters, and 15 invited speakers in our conference proceedings. Finally, we would like to reveal that our aim is to gather over 1000 participants from all over the world in the near future. Make sure that we will do our best to reach this aim as we have been doing for all our involved social and scientific works.

We would like emphasize the importance of the use of energy sources efficiently again here. We are in a new period where we should surpass traditional power generating systems, owing to critical energetic, environmental and sustainability subjects.

The existing energy situation of the world has presented some difficulties to be solved such as the integration of clean energy generation and the usage of efficient high-power and energy storage systems. The energy industry has to struggle against difficulties brought by the integration of renewable energy systems regarding with reliability and stability of the power grid. In any case, it becomes extremely significant to benefit from energy storage systems in order to stabilize and improve the efficiency of the power systems using ultimate generation batteries, ultra-capacitors, hydrogen based systems and mechanical systems, among others. Recently, the power electronics suggests effective way outs to be applied to the new spread energy grid idea.

A micro power generation with diesel systems and renewable energy is considerably depending on instabilities directly attributed to the fluctuations and the range ability of the resources. It seems extremely suggested to use storage units in order to confirm the accessibility of energy, endurance and efficiency of the system. Consistent with the formulation of the problem of energy storage, time or regularity properties tied to the existing technologies should be connected to the problem of multi-objective management of energy. The related offered proposals deal with strategies for managing energy in a power system including wind, diesel engine, flywheel, battery and super capacitor as hybridization nominees.

In concluding, I wish you every success in your deliberations and a very pleasant stay in Istanbul.

Regards,

Ahmet Selim Dalkilic

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NUMERICAL INVESTIGATION OF NATURAL CONVECTION HEAT TRANSFER IN A WAVY WALL CAVITY FILLED WITH A POROUS MEDIUM

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Keywords: Natural convection; Darcy number; Rayleigh number; wavy wall cavity

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ABSTRACT

In this article, steady natural convection inside a square cavity with wavy surface filled with a porous medium is studied numerically. The temperature for the right wall of the cavity is maintained at T_C. The wavy surface wall is located at constant heat flux and the another walls have been considered to be insulated. In present study, the governing equations are solved numerically by finite volume method. The aim of this article is investigation of Darcy and Rayleigh numbers effects on natural convection heat transfer in a wavy wall cavity. A range of parameters such as Rayleigh number ($10^3 \leq Ra \leq 10^6$) and Darcy number ($10^{-5} \leq Da \leq 10^{-1}$) are selected. It was found that the Nusselt number increases with increasing both of Rayleigh and Darcy numbers.

INTRODUCTION

Natural convection in cavity, due to its importance in many engineering applications such as crystal growth in liquid, cooling of electronic devices, nuclear reactors, coating, solidification, float glass production, food processing, microelectronic devices and solar technology, has received considerable attention in the recent decade [1-3]

In recent years, many studies have been done on the natural convection on natural convection heat transfer in square cavities. Such as, Pop and Ingham [4], Vafai [5,6]. Basak et al. [7] studied the natural convection flow in a square cavity filled with a porous medium numerically with using finite element method. In their study, the bottom wall is heated uniformly and non-uniformly, and top wall is adiabatic. Also, the cold vertical walls is maintained at constant temperature. They used Darcy–Forchheimer model to simulate the momentum transfer in the porous medium. Their results showed that the heat transfer is mainly due to conduction mechanism for $Da \leq 10^{-5}$ without regard to Ra and Pr numbers. Also, they found that at high Rayleigh numbers, the correlations between average Nusselt number and Rayleigh numbers are power law. Basak et al. [8] investigated numerically the mixed convection in a lid-driven square cavity filled with porous medium by using of finite element method. Their results showed that the effect of Peclet numbers have been further for natural convection and forced convection regimes at high Darcy number. They found that at $Da = 10^{-3}$, the local Nusselt number is uniform and it has low values for low Peclet numbers. Khanafer et al. [9] have investigated a 2-D enclosure filled with Cu-water nanofluid. They have concluded that in a specific Grashof number, with increasing of volume fraction of Cu nanoparticles, heat transfer rate, increases. Kumar et al. [10] have investigated the effect of sinusoidal surface defections on the natural convection in a porous enclosure exposed heat flux from the side wall. They have reported that the heat transfer decreases with increasing of the amplitude of the wavy wall. Ho et al. [11] have done a numerical study for investigating of the effects due to uncertainties of viscosity and thermal conductivity in natural convection heat transfer of Al_2O_3- water nano fluid in a square enclosure by finite volume method. They have found that

different models of viscosity lead to prophesy various values of Nusselt number.

The heat transfer on wavy surface wall in square cavity filled by porous media is the aim of the present research.

PHYSICAL MODEL

In Figure 1, the problem schematic view of the two-dimensional of the wavy square cavity with assumed boundary conditions are shown. As can be seen in Figure 1, the left wavy wall is assumed to be received the constant heat flux and other vertical left walls are adiabatic. The right wall is assumed to be maintained at the constant temperature (Tc). Also upper and bottom wall is considered to be insulated. The height and the width of the cavities are given by H and W. α is the amplitude and λ is wavelength of wavy wall.

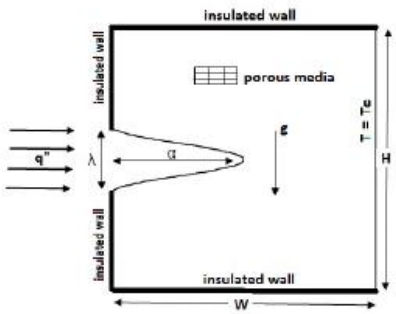


Fig 1: Schematic of the present study

the following assumptions are considered to make the model responsible to numerical simulations.

- The flow in the cavity is considered laminar, two dimensional, and incompressible.
- The thermo-physical properties are considered to be constant except for the density in the body force term in the momentum equation.

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

The governing equations are made dimensionless by using the following dimensionless variables:

$$X = \frac{x}{W}, Y = \frac{y}{W}, U = \frac{uL}{\alpha}, V = \frac{vL}{\alpha}$$
$$P = \frac{pL^2}{\rho\alpha^2}, \theta = \frac{T - T_L}{\frac{q_0''W}{k}} \quad (1)$$

where x and y are the distances measured along the horizontal and vertical directions, u and v are the velocity components in the x and y directions, respectively, q_0'' denotes the heat flux. T denotes the temperature, υ, α are kinematic viscosity and thermal diffusivity.

The governing equations for steady state and two-dimensional natural convection flow in the porous cavity using conservation of mass, momentum and energy can be written as: [12]

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \quad (2)$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + Pr\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) - \frac{Pr}{Da}U \quad (3)$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + Pr\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) - \frac{Pr}{Da}V + RaPr\theta \quad (4)$$

$$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \quad (5)$$

Boundary conditions:

Left wavy wall:

$U = 0$, $V = 0$, $\frac{\partial \theta}{\partial n} = 1$

Right flat wall:

$V = 0$, $\frac{\partial \theta}{\partial n} = 0$

Top and bottom flat walls:

$U = 0$, $V = 0$, $\frac{\partial \theta}{\partial n} = 0$

where, n is normal vector.

The local Nu number and mean Nu number (Nu_m) for the heated wall can be calculated as follows:

$$Nu = \frac{hW}{k_{bf}} \quad (6)$$

Here, h ($=\frac{q_0''}{T_s - T_L}$) is convection heat transfer coefficient. With replacing of θ from Eq. (1) into Eq. (6), therefor the Nusselt number can be calculated as follows:

$$Nu = \frac{1}{\theta_s} \quad (7)$$

For calculating, the Nu_m along the heated wall can be written:

$$Nu_m = \frac{\int_{heat\ source} Nu dn}{\int_{heat\ source} dn} \quad (8)$$

VALIDATION:

The mesh of cavity which is used for studding of flow regime and heat transfer behavior are shown In Fig. 2.

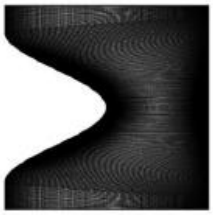


Fig 2: Sample of mesh in wavy cavity

The governing mass, momentum, and energy equations have been discretized numerically based using the finite volume method. The velocity and pressure in momentum equation is coupled by using the SIMPLE algorithm [13]. Second order central difference scheme and upwind scheme are used to discretize the convective terms in governing equations.

In this study, solution is considered converged when the summation becomes below the specific convergence criterion which is chosen as 10^{-6}.

Also, a grid independence study for determining a proper grid is examined. The average Nusselt numbers of wavy wall for this grid test are shown in Fig 3.

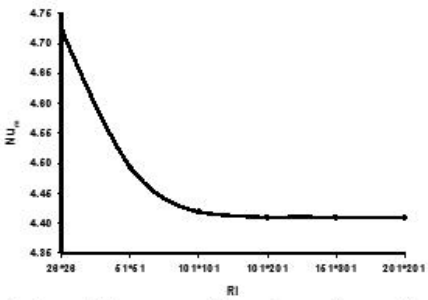


Fig 3: Variation of the mean Nusselt number with grid mesh

In this article, the model used for the validation is a square cavity that is filled with porous media [14]. The average Nusselt number for different Rayleigh number and Darcy number is calculated and presented in Table 1. As can be seen in Table 1, the present results are in good agreement with the reference [14] results.

Table1: comparison of the present results and the reference [14]

Nu_m			
Ra	Da	Present work	Reference [14]
10^5	10^{-1}	4.724	4.710

RESULTS AND DISCUSSION

In this simulation, the non-dimensional parameters were itemized as follows: Rayleigh number, Ra = 10^3 to Ra = 10^6; Prandtl number, Pr = 0.71; amplitude of wavy surface α=0.25; wavelength of wavy surface λ=0.25. The aim of this article is investigation of Darcy and Rayleigh number effects on natural convection heat transfer in wavy wall cavity.

Figure 4 shows the streamlines **contour within the wavy -wall cavity at Ra = 10^3, 10^6 for Da=10^{-4} and Da=10^{-1}.**

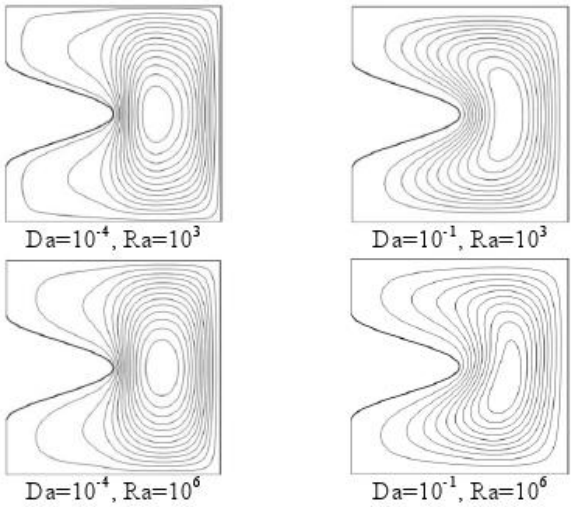


Fig 4: Flow streamlines at λ=0.5, **α=0.25**

Also, Figs. 5 show isotherms contour within the wavy-wall cavity with same condition of Figure 4.

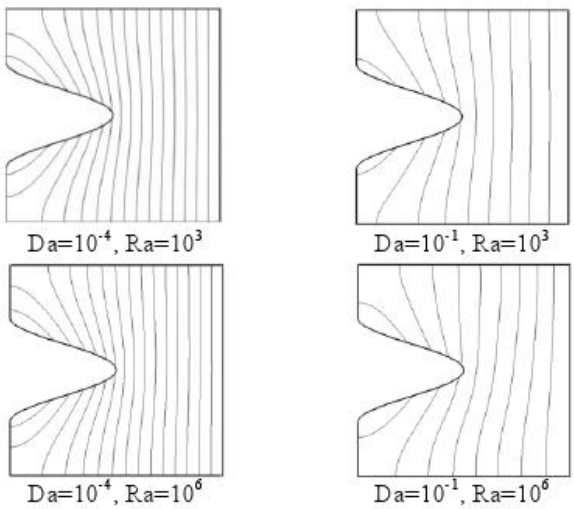


Fig 5: isotherms at λ=0.5, **α=0.25**

As can be seen in Figures 4 and 5 when Darcy number increases from 10^{-4} to 10^{-1}, flow velocity is increased. When Darcy number increases, velocity increases due to less resistances of porous medium against the fluid flow.

At low Darcy number, the temperature distribution is similar to stationary fluid and the heat transfer is due to conduction. As can be seen at Figure 5, when Darcy number decreases, the temperature contours to be concentrated near the wavy wall. Therefore thermal boundary thickness on wavy wall decreases, so temperature increases. From equation (7) concludes the mean Nusselt number as well as the heat transfer rate symbol decreases.

Rayleigh number is a parameter that has effects on heat transfer. When the Rayleigh number is low, the buoyancy effect

is weak, as a result, the flow streamlines have a symmetrical distribution (see Fig. 4). Also, heat transfer within the wavy cavity occurs primarily as a result of conduction, and therefore isotherms contours follow from the geometry profile of the cavity (see Fig. 5). When the Rayleigh number increases, the thermally-induced buoyancy effect is more powerful. As a result, heat transfer takes place primarily as a result of convection, and thus the isotherms contours twists (see Fig. 4).

In Figure 6, Variation of the mean Nusselt number with Darcy number is depicted.

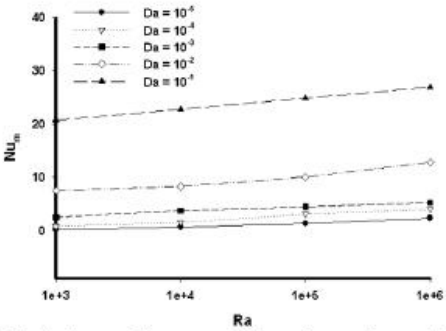
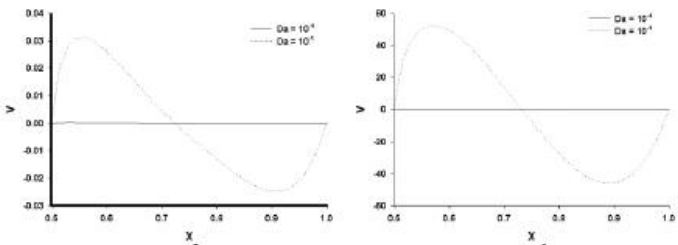


Fig 6: Variation of the mean Nusselt number with Darcy number

Figure 7, presents the non-dimentional vertical velocity and temperature profiles at Y = 0.5.



Ra=10^3 Ra=10^6

Fig 7: Effects of Darcy number on the non-dimensional vertical velocity in the wavy cavity filled with porous.

As shown in Figure 7, velocity is increased as Rayleigh number and Darcy number increased. Therefore, temperature decreased as Rayleigh number and Darcy number increased. From Equation (7) concludes the mean Nusselt number increases as Rayleigh number and Darcy number increases.

CONCLUSION

This work focuses on variation of the mean Nusselt number in natural convection heat transfer with Darcy number in wavy surface cavity. The numerical model is based on the governing equations of continuity, the Navier-stocks and energy. The results of this article are concluded as follows:

- The mean Nusselt number increased as Darcy number and Rayleigh number increased.
- Rayleigh number is a parameter that has effects on heat transfer. When the Rayleigh number is low, the buoyancy effect is weak. As a result, the flow streamlines have a symmetrical distribution.
- At low Darcy number, the temperature distribution is similar to stationary fluid and the heat transfer is due to conduction.

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