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Heatline method for the visualization of natural convection in a complicated cavity

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Abstract

In this paper, natural convection inside a two-dimensional cavity with a wavy right vertical wall has been carried out. The bottom wall is heated by a spatially varying temperature and other three walls are kept at constant lower temperature. The integral forms of the governing equations are solved numerically using finite-volume method in non-orthogonal body-fitted coordinate system. SIMPLE algorithm with higher-order upwinding scheme are used. The method of numerical visualization of heat transport for convective heat transfer by heatlines is studied. The heatfunction equation in the transformed plane is solved in terms of dimensionless variables. Results are presented in the form of streamlines, isotherms, heatlines, local and average Nusselt number distribution for a selected range of Rayleigh number (10^0–10^6). The results are presented for three different undulations (1–3) with different wave amplitude (0.00–0.10) and a fluid having Prandtl number 0.71.

Keywords: Natural convection; Numerical simulation; Heatfunction; Laminar flow; Complex geometry

1. Introduction

Streamfunction and streamlines are very convenient and being widely used tool to visualize momentum transport of fluid flow. A less common tool called heatfunction and heatlines approach are used to visualize the transfer of heat by fluid flow. An energy analog concept was first introduced by Kimura and Bejan [1], which provides a better visualization technique for transfer of heat as compared to the traditional isotherms approach.

The method has been followed and extended by several researchers in the following literature [2–10]. These heatline applications are applied to natural convection with simple geometry and boundary conditions. Costa [8,9] dealt with the conjugate heat transfer problem with variable diffusion coefficient and harmonic mean functions. Deng and Tang [10] and Costa [11] have given details about the consistency of the formulations when dealing with conjugate convection/conduction problem. Using streamlines and heatlines method, Deng et al. [12] have studied a two-dimensional, steady state and laminar natural convection in a rectangular enclosure with discrete heat sources on walls. Later on Deng et al. [13] have investigated the characteristics of the airflow and heat/contaminant transport structures in the indoor air environment by means of a convection transport visualization technique. Based on the governing equations, the fluid, heat, and contaminant transport processes are respectively described by the corresponding streamfunction, heatfunction, and massfunction. Numerical results have been presented by the contour function lines, namely, streamlines, heatlines, and masslines. Costa [14] has given a review of

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Nomenclature

g	gravitational acceleration
H	height of the enclosure
J	Jacobian
L	length of the enclosure
n	number of undulations
Nu	Nusselt number
p	dimensionless pressure
Pr	Prandtl number
P, Q	grid control functions
q_1, q_2, q_3	geometric relations between coordinate systems
Ra	Rayleigh number
S	source term
T	dimensionless temperature
ΔT	differential temperature, dimensionless
U, V	dimensionless contravariant velocity components in ξ and η direction
u, v	dimensionless velocity components in x and y direction
x, y	dimensionless Cartesian coordinates

Greek symbols

α	thermal diffusivity
ξ, η	dimensionless curvilinear coordinates
ϕ	general variable representing u, v and T
λ	wave amplitude
Φ	heatfunction
ψ	streamfunction

Subscripts

av	average
c	cold wall
h	hot wall
l	local
max	maximum
x, y, ξ, η	derivative relative to x, y, ξ, η, respectively

Superscript

*	dimensional form

the Bejan's heatline and massline approach for convection visualization and approach.

Recently, Dalal and Das [15] have studied natural convection in a cavity with one wavy wall of different undulations. The bottom wall was heated by a sinusoidally varying temperature and the other three walls are maintained at cold conditions. In the present work, the heatfunction equation has been modified and solved for a complex geometry. The visualization of the transfer of heat for the convection at Rayleigh number 10^0–10^6 for one-, two- and three-undulations have been done. The amplitude of undulation is varied from 0.00 to 0.10.

2. Governing equations and boundary conditions

The geometry of the two-dimensional square cavity with wavy right vertical wall filled with viscous fluid is shown in Fig. 1. The bottom wall temperature is considered to be spatially varying with sinusoidal temperature distribution. The other three walls are considered to be of constant temperature. The expression of the wavy wall is given by

$$f(y) = 1 - \lambda + \lambda \times \cos(2\pi n y) \quad (1)$$

where n is the number of undulations. Three different cases with one-, two- and three-undulations are studied. The wave amplitude (λ) for three cases is varied from 0.00 to 0.10. The fluid considered in this study is air ($Pr = 0.71$). The Rayleigh number is varied from 10^0 to 10^6.

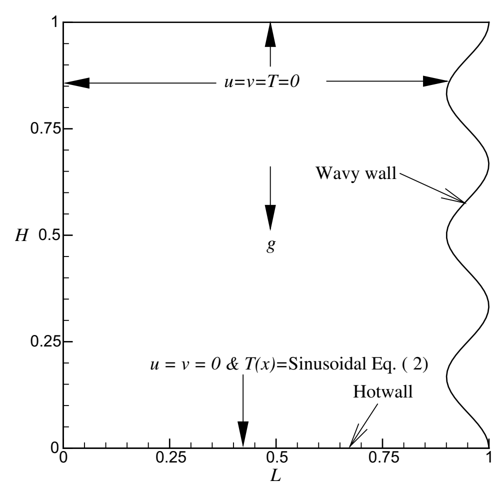

Fig. 1. Flow configuration and boundary condition for three undulations.

The details of the nondimensional governing equations in the physical plane and in the computational plane (ξ, η) are given in [15] along with the boundary conditions.

2.1. Heatfunction equation

To visualize the transfer of heat by fluid flow, an energy analog concept, heatfunction and heatlines, was introduced by Kimura and Bejan [1] which provides a better visualization technique as compared to the traditional isotherm approach. The dimensionless form of heatfunction, Φ, in two-dimension is defined as [1]