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Simulation of forced convection a Boundary Element Method for the laminar viscous dissipation of flow through a straight regular polygonal duct with uniform heat flux

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Abstract

The paper presents a numerical study to investigate the effect of the viscous dissipation of laminar flow through a straight regular polygonal duct on the forced convection with constant axial wall heat flux with constant peripheral wall temperature. Both the wall heating case and the wall cooling case are considered. Applying the velocity profile obtained for the duct laminar flow and the energy equation with the viscous dissipation term was exactly solved for the constant wall heat flux using the Boundary Element Method (BEM). Nusselt numbers were obtained for flows having a different number of sides of a regular polygonal duct and Brinkman numbers.

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Keywords: viscous dissipation; heat transfer; forced convection; Brinkman number; boundary element method

1. Introduction

The effect of viscous dissipation of laminar forced convection in ducts has been investigated by many authors. The temperature distribution in a circular tube due to the energy dissipation of viscous flow was first analyzed by Brinkman [1]. Taygi [2] investigated the effect of viscous dissipation on the fully developed laminar forced convection in circular, equilateral triangular and elliptic tubes with constant wall temperature. Zanchini [3] studied the asymptotic behavior of laminar forced convection in a circular tube, for a Newtonian fluid at constant properties

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by taking into account the viscous dissipation effects. Barletta and Rossi di Schio [4] analyzed the laminar forced convection with viscous dissipation in a circular duct with axially periodic wall heat flux. Aydin [5,6] performed a wide study on the effect of viscous dissipation on the fully developed laminar forced convection in a circular tube with constant heat flux and constant wall temperature. Avci and Aydin [7] studied the effects of the viscous dissipation on steady state laminar heat transfer in the concentric annular pipe flow. Morini et al. [8] analytically determined the temperature distribution in the cross-section of a rectangular duct, under the conditions of Newtonian and incompressible fluid with viscous dissipation. Morini and Spiga [9] analytically calculated the Nusselt numbers in a rectangular duct, in fully developed laminar flow with viscous dissipation, for any combination of heated and adiabatic sides of the duct. The problem of flow in a trapezoidal microchannel tube with viscous dissipation effect has been solved by Morini and Spiga [10] using a Rayleigh-Ritz-Galerkin finite element method. The steady state laminar heat transfer with viscous dissipation in a plane duct has been investigated extensively in references [11,12,13].

Nomenclature

A	cross sectional area, m^2
Br_q	Brinkman number defined by equation (6)
c_p	specific heat capacity, J/kg/^{o}C
D_h	hydraulic diameter, m
k	thermal conductivity, W/m/K
L	wetted perimeter of the cross-section, m
n	number of sides of a regular polygonal duct
Nu	Nusselt number defined by equation (9)
Nu_0	Nusselt number when Br=0
p	pressure, Pa
Re	Reynolds number
q_w	total wall heat flux density, W/m^2
q_{vd}	wall heat flux density generated by viscous dissipation, W/m^2
u	velocity, m/s
T	temperature, ^{o}C
x,y,z	Cartesian coordinate, m

Greek symbols

μ	dynamic viscosity, kg/m/s
ρ	density, kg/m^3
σ	shape coefficient for Br_q
Φ	viscous dissipation function, Pa/s

Subscripts

b	bulk
m	mean
s	singular
w	wall
vd	viscous dissipation

The aim of this work is to investigate the effect of viscous dissipation on laminar forced convective flow in a regular polygon ducts with a different number n of sides. Shahsavari et al. [14] provided a compact relationship for variation of Nusselt number with number of sides of a regular polygonal duct for forced convection. No compact relationship was found for the Nusselt number vs the Brinkman number and n for a regular polygonal duct for forced convection with viscous dissipation. The influence of Brinkman on the Nusselt for different values of n is obtained for the constant wall heat flux boundary condition.

2. Mathematical model

In this section, the governing equations and boundary conditions are presented. Reference will be made to the laminar, incompressible and forced convection in a straight duct for a Newtonian fluid with a constant thermal conductivity k and a constant dynamic viscosity μ with a fully developed profile of velocity and for flow with negligible gravitational effects. With these assumptions, the continuity (1), momentum (2) and energy equations (3) for steady, two-dimensional flow in duct are

$$\frac{\partial u_z}{\partial z} = 0 \tag{1}$$