Forced turbulent heat convection in a square duct with non-uniform wall temperature ☆

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ABSTRACT

In the present work, the numerical simulation to calculate the problem of the turbulent convection with non-uniform wall temperature in a square cross-section duct was adopted. To solve this problem some assumptions for the flow, such as: the condition of fully developed turbulence and incompressible flow have been assumed. The methodology of the dimensionless energy equation was used to calculate the fluid temperature field in the square cross-section in function of the non-uniform wall temperatures prescribed. Numerical simulations were done using two different turbulent models to resolve the momentum equations and two more models to resolve the energy equation. The models of turbulence k–ε Nonlinear Eddy Viscosity Model (NLEVM) and the Reynolds Stress Model (RSM) were used to determine the turbulent intensities as well as the profiles of axial and secondary mean velocities. The turbulence model RSM was simulated using a commercial software. The thermal field was determined from other two models: Simple Eddy Diffusivity (SED), based in the hypothesis of the constant turbulent Prandtl number; and Generalized Gradient Diffusion Hypothesis (GGDH). In this last model, as the turbulent heat transfer depends on the shear tensions, the anisotropy is considered. These two last equation models of the energy equation of the fluid have been implemented in FORTRAN, a code of programming. The performances of the models were evaluated by validating them based in the experimental and numerical results published in the literature. Two important parameters of great interest in engineering are presented: the friction factor and the Nusselt number. The results of this investigation allow the evaluation of the behavior of the turbulent flow and convective heat fluxes for different square cross-sectional sections throughout the direction of the main flow, which is mainly influenced by the temperature distribution in the wall.

1. Introduction

Square ducts are widely used in heat transfer devices. For instance in compact heat exchangers, gas turbine cooling systems, cooling channels in combustion chambers and nuclear reactors.

The forced turbulent heat convection in a square duct is one of the fundamental problems in the thermal science and fluid mechanics. Recently, Qin and Plecther [1] showed that the Prandtl's secondary flow of the second kind has a significant effect on the transport of heat and momentum as revealed by the recent Large Eddy Simulation (LES) technique.

Several experimental and numerical studies have been conducted on turbulent flow though a non-circular duct, specifically, (Nikuradse [2]; Gessner and Emery [3]; Gessner and Po [4]; Melling and Whitelaw [5]; Nakayama et al. [6]; Myon and Kobayashi [7]; Assato [8]; Assato and De Lemos [9]; Home et al. [10]; Luo et al. [11]; Ergin et al. [12] and others). Similarly important works in the turbulent heat convection

were developed (Launder and Ying [13]; Emery et al. [14]; Hirota et al. [15]; Rokni [16]; Hongxing [17]; Yang and Hwang [18]; Park [19]; Zhang et al. [20]; Zheng et al. [21]; Su and Da Silva Neto [22]; Saidi and Sundén [23]; Rokni [24]; Valencia [25]; Sharatchandra and Rhode [26]; Campo et al. [27]; Rokni and Sundén [28]; Yang and Ebadian [29] and others).

The experimental work of Melling and Whitelaw [5] shows detailed characteristics of turbulent flow in a rectangular duct where they used a laser-Doppler anemometer to report the axial development of the mean velocity, secondary mean velocity, etc. Nakayama et al. [6] show the analysis of the fully developed flow field in ducts of rectangular and trapezoidal cross-sections using a finite-difference method with the model of Launder and Ying [13]. On the other hand, Hirota et al. [15] present an experimental work on the turbulent heat transfer in a square duct; they show detailed characteristics of turbulent flow and temperature field. Likewise, Rokni [16] carried out a comparison of four different turbulence models for predicting the turbulent Reynolds stresses and three turbulent heat flux models for ducts square.

In the literature on turbulence modeling it is well known that Linear Eddy Viscosity Models (LEVM) can give rise to inaccurate