Laminar Forced Convection Heat Transfer in Square Duct with Heated and Adiabatic Walls at Constant Axial Heat Flux

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Square ducts are used in many thermal-flow problems, among others as heat micro-heat exchangers. Forced convection in straight ducts with a square cross-section is also the subject of research in micro-channels. Nusselt numbers solutions are known in the literature as a function of the following geometry of adiabatic wall systems: parallel adiabatic walls, adiabatic walls forming an angle and a U-section. Nusselt numbers solutions for a square channel buried in isolation were not found in the literature (Fig.1).

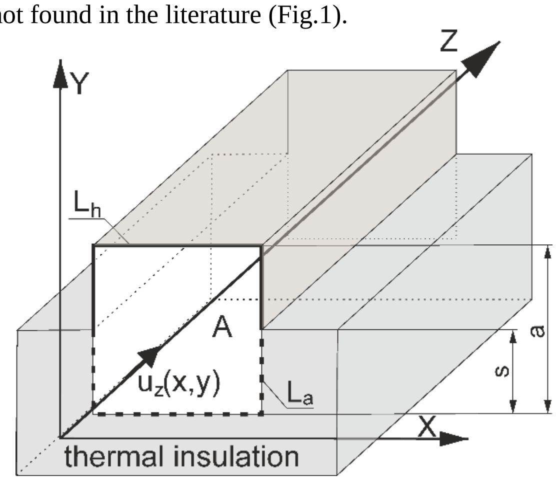


FIGURE 1. Geometry and boundary conditions

The purpose of the work is to determine the number of Nusselt as a function of the depth of the adiabatic wall cavity (Fig. 1):

$$Nu = f({}^{s}/_{a}), \tag{1}$$

The investigation of heat transfer in a ducts with insulated walls of the tube cross section is very complicated, because it requires a numerical method e.g. the finite –integral transform method, the finite difference method, the finite element method or the finite volume method.

Computational analysis will be carried out for 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 (2), momentum (3) and energy equations (4) for steady, two-dimensional flow in the duct are:

$$\frac{\partial u_z}{\partial z} = 0, \tag{2}$$

$$\mu\left(\frac{\partial^2 u_z}{\partial x^2} + \frac{\partial^2 u_z}{\partial y^2}\right) = \frac{\partial p}{\partial z}, \qquad \frac{\partial p}{\partial x} = \frac{\partial p}{\partial y} = 0, \tag{3}$$

$$k\nabla^2 T = \rho c_p \frac{\partial T}{\partial z} u_z. \tag{4}$$

where u_z is the axial velocity.

In order to determine the velocity field, the analytical solution was used, while the temperature field was determined from the energy equation (4). Equation (4) has been solved by the boundary element method. The work also presents sample temperature fields and heatlines for selected Nusselt numbers. The results are presented and discussed in graphs and tables. The newly developed correlations for Nusselt numbers as a function of the ratio of depth of an adiabatic wall to height of the vertical wall can be a powerful tool for the optimization and design of many different systems which permit the investigation of the laminar forced convection in a square duct with an adiabatic side. Figure 2 shows the determined dependence of the Nusselt number on the square channel cavity in thermal insulation (*s*/*a*), while Figures 3a-c show examples of solutions of dimensionless temperature fields and heatlines for selected geometric parameters *s*/*a*.

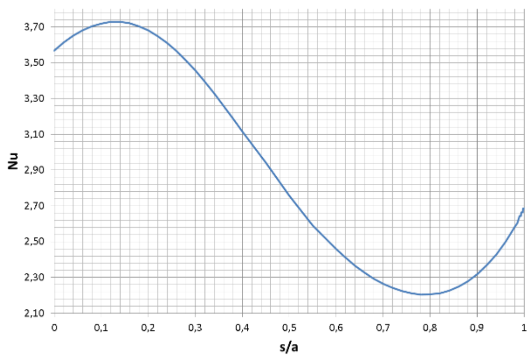
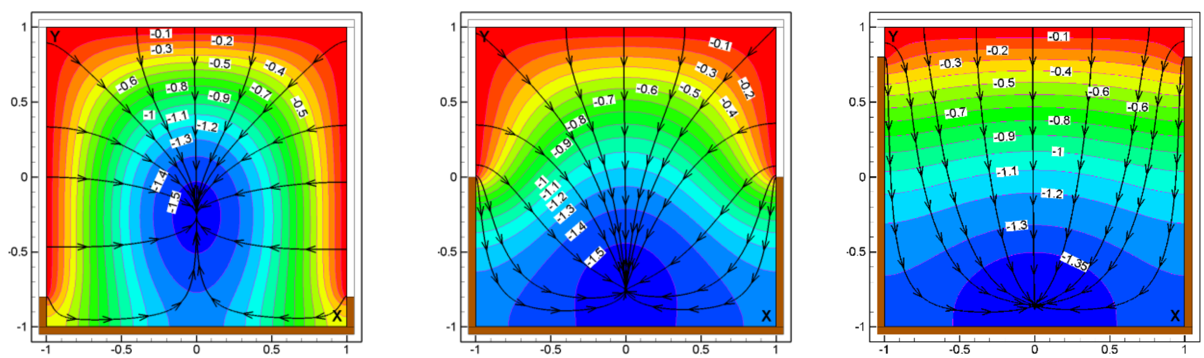


FIGURE 2. Plot of Nu vs *s/a*



(a) (b) (c)

FIGURE 3. Dimensional temperature field and heat flow lines for selected geometric parameters *s/a*: (a) *s/a*=0.1 (Nu=3.72), (b) *s/a*=0.5 (Nu=2.76), (c) *s/a*=0.9 (Nu=2.32)

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