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MODELING OF HEAT TRANSFER AND FLUID FLOW IN A RECTANGULAR CHANNEL WITH AN OBSTACLE

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Abstract. Heat transfer and fluid flow in the rectangular channel with an obstacle are considered. The problem is described by the Fourier-Kirchhoff equation, Navier-Stokes equations and continuity equation supplemented by appropriate boundary and initial conditions. To solve this system of equations the finite difference method with a staggered grid is used. The results of computations obtained using authorial computer program are compared with ANSYS Fluent simulation. Computations are carried out for obstacles of various sizes and positions, and on this basis the conclusions are formulated.

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Keywords: *channel with an obstacle, Fourier-Kirchhoff's equation, Navier-Stokes equations, finite difference method*

1. Introduction

In the paper, the two-dimensional, transient, laminar fluid flow in the channel with an obstacle is analyzed. The temperature of the channel walls is equal to T_w and is the same as the obstacle temperature. The fluid temperature at the channel inlet is equal to $T_{in} < T_w$, while the fluid velocity at the channel inlet is equal to v_{in}. Fluid flow is described by the Navier-Stokes equations and continuity equation, the heat transfer is described by the Fourier-Kirchhoff equation. These equations are supplemented by appropriate boundary and initial conditions.

This system of coupled equations is solved using the finite difference method with a staggered grid. The comparison between the results obtained using an authorial computer program and the ANSYS Fluent simulation are performed. Computations are carried out for obstacles of various sizes and positions.

The goal is to determine what effect the size and location of the obstacle have on temperature and velocity distributions.

2. Formulation of the problem

Two-dimensional, transient, laminar fluid flow in the channel with an obstacle located on the lower wall is considered, as shown in Figure 1. The channel consists of two parallel plates of length *ly*, and the distance between them is equal to *lx*. The obstacle height is *H* and the width is *W*. The distance of the obstacle from the inlet of the channel is equal to *l*.

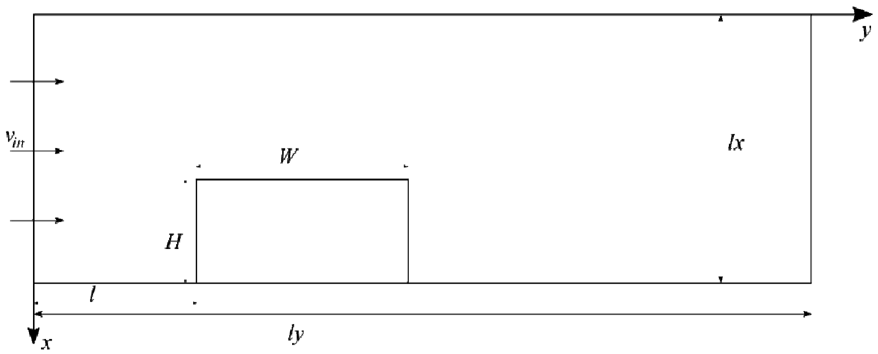

Fig. 1. Computational domain

The mathematical model of the analyzed process consists of the following equations, e.g. [1]

– *x* momentum equation

$$\frac{\partial u}{\partial t}=-\frac{\partial\left(u^2\right)}{\partial x}-\frac{\partial(uv)}{\partial y}-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{1}$$

– *y* momentum equation

$$\frac{\partial v}{\partial t}=-\frac{\partial(uv)}{\partial x}-\frac{\partial\left(v^2\right)}{\partial y}-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{2}$$

– continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{3}$$

– Fourier-Kirchhoff equation

$$\frac{\partial T}{\partial t}+\frac{\partial(uT)}{\partial x}+\frac{\partial(vT)}{\partial y}=a\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

where u, v are the velocity components in the x and y direction, p is the pressure, ρ is the density, ν is the kinematic viscosity, $a = \lambda/(c\rho)$ (λ is the thermal conductivity, c is the specific heat), T is the temperature and t denotes the time.

It should be noted that the equations (1) and (2) are slightly differently written than standard ones, but it is easy to check that

$$\begin{gathered}\frac{\partial\left(u^2\right)}{\partial x}+\frac{\partial(uv)}{\partial y}=2u\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}v+u\frac{\partial v}{\partial y}=\\ u\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\end{gathered}\tag{5}$$

and

$$\begin{gathered}\frac{\partial(uv)}{\partial x}+\frac{\partial\left(v^2\right)}{\partial y}=\frac{\partial u}{\partial x}v+u\frac{\partial v}{\partial x}+2v\frac{\partial v}{\partial y}=\\ v\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\end{gathered}\tag{6}$$

In the above formulas, the continuity condition (3) is taken into account. In a similar way one obtains (c.f. equation (4))

$$\begin{gathered}\frac{\partial(uT)}{\partial x}+\frac{\partial(vT)}{\partial y}=\frac{\partial u}{\partial x}T+u\frac{\partial T}{\partial x}+\frac{\partial v}{\partial y}T+v\frac{\partial T}{\partial y}=\\ T\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\end{gathered}\tag{7}$$

It should be emphasized that the constant temperature T_w in the obstacle subdomain is assumed here.

The system of equations (1)-(4) should be supplemented by appropriate boundary and initial conditions. The fluid velocity and the temperature at the channel inlet are assumed uniform, namely $v = v_{in}$ and $T = T_{in}$, while $\partial u/\partial n = 0$ ($\partial(\cdot)/\partial n$ denotes the normal derivative). At the walls $x = 0$, $x = lx$ the boundary conditions $u = 0$ and $\partial v/\partial n = 0$ are accepted. At the channel outlet $\partial u/\partial n = 0$, $v = v_{in}$, $\partial T/\partial n = 0$. The temperature of the walls $x = 0$, $x = lx$ is equal to T_w and is the same as the obstacle temperature. The initial conditions are also known: $u = v = 0$ and $T = T_{in}$.

3. Method of solution

To solve the problem formulated, the finite difference method is used. At first, the staggered grid [1-5], as shown in Figure 2, is introduced.

Let us denote $u_{i,j}^f = u(ih, jk, f\Delta t)$, where h is the grid step in x direction, k is the grid step in y direction, Δt is the time step, $i = 0, 2, 4, ..., m$, $j = 1, 3, ..., n-1$, $f = 0, 1, 2, ..., F$, and $v_{i,j}^f = v(ih, jk, f\Delta t)$, where $i = 1, 3, ..., m-1$, $j = 0, 2, ..., n$.

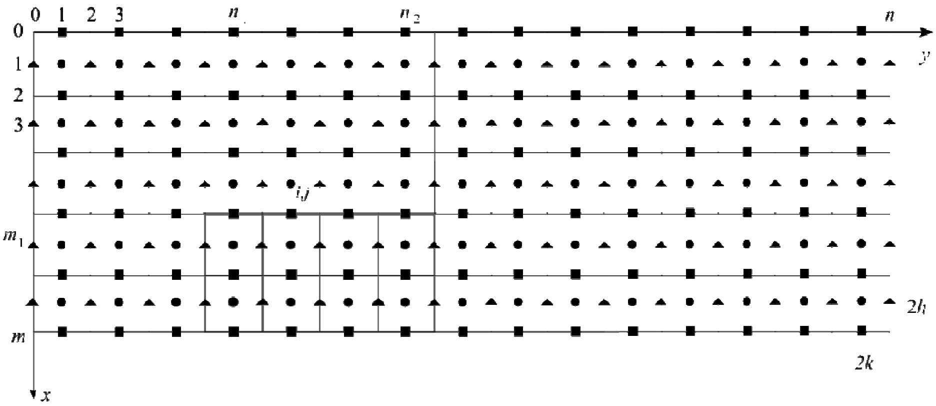

Fig. 2. Staggered grid: ● - pressure, temperature, ■ - velocity component u, ▲ - velocity component v

The finite difference approximation of equations (1) and (2) using an explicit scheme can be written in the form ($i = 2, 4, ..., m-2, j = 1, 3, ..., n-1$)

$$\begin{gathered}\frac{\bar{u}_{i,j}^{f+1} - 0.25\left(u_{i-2,j}^f + u_{i+2,j}^f + u_{i,j-2}^f + u_{i,j+2}^f\right)}{\Delta t} = -\frac{\left(u^2\right)_{i+2,j}^f - \left(u^2\right)_{i-2,j}^f}{4h} - \\ \frac{(uv)_{i,j+1}^f - (uv)_{i,j-1}^f}{2k} + \nu\left(\frac{u_{i-2,j}^f - 2u_{i,j}^f + u_{i+2,j}^f}{4h^2} + \frac{u_{i,j-2}^f - 2u_{i,j}^f + u_{i,j+2}^f}{4k^2}\right)\end{gathered} \tag{8}$$

and ($i = 1, 3, ..., m-1, j = 2, 4, ..., n-2$)

$$\begin{gathered}\frac{\bar{v}_{i,j}^{f+1} - 0.25\left(v_{i-2,j}^f + v_{i+2,j}^f + v_{i,j-2}^f + v_{i,j+2}^f\right)}{\Delta t} = -\frac{(uv)_{i+1,j}^f - (uv)_{i-1,j}^f}{2h} - \\ \frac{\left(v^2\right)_{i,j+2}^f - \left(v^2\right)_{i,j-2}^f}{4k} + \nu\left(\frac{v_{i-2,j}^f - 2v_{i,j}^f + v_{i+2,j}^f}{4h^2} + \frac{v_{i,j-2}^f - 2v_{i,j}^f + v_{i,j+2}^f}{4k^2}\right)\end{gathered} \tag{9}$$

A dash above u and v indicates that the components related to the pressure are omitted (c.f. equations (1), (2)) [5].
The stability conditions for equations (8) and (9) have the form [5]

$$1 - \frac{\nu\Delta t}{2h^2} - \frac{\nu\Delta t}{2k^2} \ge 0, \quad \frac{|u|\Delta t}{2h} + \frac{|v|\Delta t}{2k} \le 1 \tag{10}$$

To take into account the boundary conditions, the fictitious nodes outside the domain are introduced and then

$$u_{0,j}^f = 0, u_{m,j}^f = 0, \; j = 1,3,...,n-1, \quad u_{i,-1}^f = u_{i,1}^f, \quad u_{i,n+1}^f = u_{i,n-1}^f, \; i = 0,2,...,m \tag{11}$$

$$v_{i,0}^f = v_{in},\, v_{i,n}^f = v_{in},\, i = 1,3,...,m-1, \quad v_{-1,j}^f = v_{1,j}^f, \quad v_{m+1,j}^f = v_{m-1,j}^f,\, j = 0,2,...,n \quad (12)$$

Average values of u and v are defined, namely

$$\begin{aligned} u_{i+1,j}^f &= \frac{u_{i,j}^f + u_{i+2,j}^f}{2}, \quad u_{i-1,j}^f = \frac{u_{i,j}^f + u_{i-2,j}^f}{2} \\ (uv)_{i,j+1}^f &= \left(\frac{u_{i,j}^f + u_{i,j+2}^f}{2}\right)\left(\frac{v_{i-1,j+1}^f + v_{i+1,j+1}^f}{2}\right) \\ (uv)_{i,j-1}^f &= \left(\frac{u_{i,j}^f + u_{i,j-2}^f}{2}\right)\left(\frac{v_{i-1,j-1}^f + v_{i+1,j-1}^f}{2}\right) \end{aligned} \quad (13)$$

$$\begin{aligned} v_{i,j+1}^f &= \frac{v_{i,j}^f + v_{i,j+2}^f}{2}, \quad v_{i,j-1}^f = \frac{v_{i,j}^f + v_{i,j-2}^f}{2} \\ (uv)_{i+1,j}^f &= \left(\frac{u_{i+1,j-1}^f + u_{i+1,j+1}^f}{2}\right)\left(\frac{v_{i,j}^f + v_{i+2,j}^f}{2}\right) \\ (uv)_{i-1,j}^f &= \left(\frac{u_{i-1,j-1}^f + u_{i-1,j+1}^f}{2}\right)\left(\frac{v_{i,j}^f + v_{i-2,j}^f}{2}\right) \end{aligned} \quad (14)$$

Introducing (13) into (8) and (14) into (9) one obtains

$$\overline{u}_{i,j}^{f+1} = \frac{1}{4}\left(u_{i-2,j}^f + u_{i+2,j}^f + u_{i,j-2}^f + u_{i,j+2}^f\right) + A_{i,j}^f \Delta t \quad (15)$$

$$\begin{aligned} A_{i,j}^f &= -\frac{\left(u_{i+2,j}^f\right)^2 - \left(u_{i-2,j}^f\right)^2}{4h} - \\ &\frac{\left(u_{i,j}^f + u_{i,j+2}^f\right)\left(v_{i-1,j+1}^f + v_{i+1,j+1}^f\right) - \left(u_{i,j}^f + u_{i,j-2}^f\right)\left(v_{i-1,j-1}^f + v_{i+1,j-1}^f\right)}{8k} + \\ &\nu\left(\frac{u_{i-2,j}^f - 2u_{i,j}^f + u_{i+2,j}^f}{4h^2} + \frac{u_{i,j-2}^f - 2u_{i,j}^f + u_{i,j+2}^f}{4k^2}\right) \end{aligned} \quad (16)$$

and

$$\overline{v}_{i,j}^{f+1} = \frac{1}{4}\left(v_{i-2,j}^f + v_{i+2,j}^f + v_{i,j-2}^f + v_{i,j+2}^f\right) + B_{i,j}^f \Delta t \quad (17)$$

$$B_{i,j}^{f}=-\frac{\left(u_{i+1,j-1}^{f}+u_{i+1,j+1}^{f}\right)\left(v_{i,j}^{f}+v_{i+2,j}^{f}\right)-\left(u_{i-1,j-1}^{f}+u_{i-1,j+1}^{f}\right)\left(v_{i,j}^{f}+v_{i-2,j}^{f}\right)}{8h}-$$
$$\frac{\left(v_{i,j+2}^{f}\right)^{2}-\left(v_{i,j-2}^{f}\right)^{2}}{4k}+\nu\left(\frac{v_{i-2,j}^{f}-2v_{i,j}^{f}+v_{i+2,j}^{f}}{4h^{2}}+\frac{v_{i,j-2}^{f}-2v_{i,j}^{f}+v_{i,j+2}^{f}}{4k^{2}}\right) \tag{18}$$

For the nodes (i+1, j) and (i–1, j) the following approximation of equation (1) is proposed

$$\frac{u_{i+1,j}^{f+1}-\bar{u}_{i+1,j}^{f+1}}{\Delta t}=-\frac{p_{i+2,j}^{f+1}-p_{i,j}^{f+1}}{2h\rho},\quad \frac{u_{i-1,j}^{f+1}-\bar{u}_{i-1,j}^{f+1}}{\Delta t}=-\frac{p_{i,j}^{f+1}-p_{i-2,j}^{f+1}}{2h\rho} \tag{19}$$

while for the nodes (i, j+1) and (i, j–1) the approximation of equation (2) is as follows

$$\frac{v_{i,j+1}^{f+1}-\bar{v}_{i,j+1}^{f+1}}{\Delta t}=-\frac{p_{i,j+2}^{f+1}-p_{i,j}^{f+1}}{2k\rho},\quad \frac{v_{i,j-1}^{f+1}-\bar{v}_{i,j-1}^{f+1}}{\Delta t}=-\frac{p_{i,j}^{f+1}-p_{i,j-2}^{f+1}}{2k\rho} \tag{20}$$

The continuity condition (3) is also approximated (i = 1, 3, ..., m – 1, j = 1, 3, ..., n – 1)

$$\frac{u_{i+1,j}^{f+1}-u_{i-1,j}^{f+1}}{2h}+\frac{v_{i,j+1}^{f+1}-v_{i,j-1}^{f+1}}{2k}=0 \tag{21}$$

Taking into account the dependencies (19) and (20), the equation (21) has a form

$$\frac{\bar{u}_{i+1,j}^{f+1}-\bar{u}_{i-1,j}^{f+1}}{2h}+\frac{\bar{v}_{i,j+1}^{f+1}-\bar{v}_{i,j-1}^{f+1}}{2k}-\frac{\Delta t}{4\rho h^{2}}\left(p_{i-2,j}^{f+1}-2p_{i,j}^{f+1}+p_{i+2,j}^{f+1}\right)-$$
$$\frac{\Delta t}{4\rho k^{2}}\left(p_{i,j-2}^{f+1}-2p_{i,j}^{f+1}+p_{i,j+2}^{f+1}\right)=0 \tag{22}$$

Newton's method for solving the system of algebraic equations (22) is used here. Let [5]

$$D\left(p_{i,j}^{s-1}\right)=\frac{\bar{u}_{i+1,j}^{f+1}-\bar{u}_{i-1,j}^{f+1}}{2h}+\frac{\bar{v}_{i,j+1}^{f+1}-\bar{v}_{i,j-1}^{f+1}}{2k}-\frac{\Delta t}{4\rho h^{2}}\left(p_{i-2,j}^{s-1}-2p_{i,j}^{s-1}+p_{i+2,j}^{s-1}\right)-$$
$$\frac{\Delta t}{4\rho k^{2}}\left(p_{i,j-2}^{s-1}-2p_{i,j}^{s-1}+p_{i,j+2}^{s-1}\right) \tag{23}$$

and then

$$p_{i,j}^{s} = p_{i,j}^{s-1} - \frac{D\left(p_{i,j}^{s-1}\right)}{\partial D\left(p_{i,j}^{s-1}\right) / \partial p_{i,j}^{s-1}} \tag{24}$$

where s is the number of iteration and

$$\frac{\partial D\left(p_{i,j}^{s-1}\right)}{\partial p_{i,j}^{s-1}} = \frac{\Delta t}{2\rho h^2} + \frac{\Delta t}{2\rho k^2} \tag{25}$$

Thus, for $s = 1$ in the nodes the arbitrary values of the pressure are assumed (e.g. zero). In the next iterations, the values of pressure are calculated using the formula

$$p_{i,j}^{s} = p_{i,j}^{s-1} - \frac{2\rho h^2 k^2}{\Delta t\left(h^2 + k^2\right)} D\left(p_{i,j}^{s-1}\right), \quad s = 1, 2, ..., S \tag{26}$$

Approximation of boundary conditions is as follows

$$\begin{gathered} p_{i,-1}^{s-1} = p_{i,1}^{s-1},\ p_{i,n+1}^{s-1} = p_{i,n-1}^{s-1},\ i = 1,3,...,m-1 \\ p_{-1,j}^{s-1} = p_{1,j}^{s-1},\ p_{m+1,j}^{s-1} = p_{m-1,j}^{s-1},\ j = 1,3,...,n-1 \end{gathered} \tag{27}$$

The calculations are repeated until $D(p_{i,j}^{s-1})$ is almost zero. The final pressure distribution corresponds to the moment t^{f+1}.
Finally, the velocity components are calculated (i = 2, 4, ..., m – 2, j = 1, 3, ..., n – 1) - c.f. formula (19)

$$u_{i,j}^{f+1} = \overline{u}_{i,j}^{f+1} - \frac{\Delta t}{2h\rho}\left(p_{i+1,j}^{f+1} - p_{i-1,j}^{f+1}\right) \tag{28}$$

and (i = 1, 3, ..., m – 1, j = 2, 4, ..., n – 2) - c.f. formula (20)

$$v_{i,j}^{f+1} = \overline{v}_{i,j}^{f+1} - \frac{\Delta t}{2k\rho}\left(p_{i,j+1}^{f+1} - p_{i,j-1}^{f+1}\right) \tag{29}$$

The following approximation of equation (4) is proposed (i = 1, 3, ..., m – 1, j = 1, 3, ..., n – 1)

$$\begin{gathered} \frac{T_{i,j}^{f+1} - 0.25\left(T_{i-2,j}^{f} + T_{i+2,j}^{f} + T_{i,j-2}^{f} + T_{i,j+2}^{f}\right)}{\Delta t} + \frac{(uT)_{i+1,j}^{f} - (uT)_{i-1,j}^{f}}{2h} + \\ \frac{(vT)_{i,j+1}^{f} - (vT)_{i,j-1}^{f}}{2k} = a\left(\frac{T_{i-2,j}^{f} - 2T_{i,j}^{f} + T_{i+2,j}^{f}}{(2h)^2} + \frac{T_{i,j-2}^{f} - 2T_{i,j}^{f} + T_{i,j+2}^{f}}{(2k)^2}\right) \end{gathered} \tag{30}$$

where [5]

$$\left(uT\right)_{i+1,j}^{f}=\begin{cases}u_{i+1,j}^{f}T_{i,j}^{f}, & u_{i+1,j}^{f}\geq 0\\ u_{i+1,j}^{f}T_{i+2,j}^{f}, & u_{i+1,j}^{f}<0\end{cases},\quad \left(uT\right)_{i-1,j}^{f}=\begin{cases}u_{i-1,j}^{f}T_{i-2,j}^{f}, & u_{i-1,j}^{f}\geq 0\\ u_{i-1,j}^{f}T_{i,j}^{f}, & u_{i-1,j}^{f}<0\end{cases} \tag{31}$$

$$\left(vT\right)_{i,j+1}^{f}=\begin{cases}v_{i,j+1}^{f}T_{i,j}^{f}, & v_{i,j+1}^{f}\geq 0\\ v_{i,j+1}^{f}T_{i,j+2}^{f}, & v_{i,j+1}^{f}<0\end{cases},\quad \left(vT\right)_{i,j-1}^{f}=\begin{cases}v_{i,j-1}^{f}T_{i,j-2}^{f}, & v_{i,j-1}^{f}\geq 0\\ v_{i,j-1}^{f}T_{i,j}^{f}, & v_{i,j-1}^{f}<0\end{cases} \tag{32}$$

Finally

$$\begin{gathered}T_{i,j}^{f+1}=\frac{1}{4}\left(T_{i-2,j}^{f}+T_{i+2,j}^{f}+T_{i,j-2}^{f}+T_{i,j+2}^{f}\right)-\Delta t\frac{\left(uT\right)_{i+1,j}^{f}-\left(uT\right)_{i-1,j}^{f}}{2h}-\\ \Delta t\frac{\left(vT\right)_{i,j+1}^{f}-\left(vT\right)_{i,j-1}^{f}}{2k}+a\Delta t\left(\frac{T_{i-2,j}^{f}-2T_{i,j}^{f}+T_{i+2,j}^{f}}{4h^{2}}+\frac{T_{i,j-2}^{f}-2T_{i,j}^{f}+T_{i,j+2}^{f}}{4k^{2}}\right)\end{gathered} \tag{33}$$

The stability condition takes a form

$$1-\frac{a\Delta t}{2h^{2}}-\frac{a\Delta t}{2k^{2}}\geq 0 \tag{34}$$

It should be noted that the velocities normal to the obstacle are set to zero and the tangential velocities are free slip boundary conditions [5]

$$\begin{gathered}u_{m_1-1,j}^{f}=0,\quad u_{m,j}^{f}=0,\qquad j=n_1,n_1+2,...,n_2\\ u_{i,n_1}^{f}=u_{i,n_1-2}^{f},\ u_{i,n_2}^{f}=u_{i,n_2+2}^{f},\ i=m_1-1,m_1+1,...,m\end{gathered} \tag{35}$$

$$\begin{gathered}v_{i,n_1-1}^{f}=0,\quad v_{i,n_2+1}^{f}=0,\qquad i=m_1,m_1+2,...,m-1\\ v_{m_1,j}^{f}=v_{m_1-2,j}^{f},\ v_{m-1,j}^{f}=v_{m+1j}^{f},\ j=n_1-1,n_1+1,...,n_2+1\end{gathered} \tag{36}$$

4. Results of computations

The rectangular channel of dimensions lx = 0.1 m and ly = 0.4 m is considered. The dimensions of an obstacle are equal to H = 0.06 m and W = 0.06 m. The distance of the obstacle from the inlet of the channel is equal to l = 0.1 m. The following parameters of water are accepted: density ρ = 998.3 kg/m^3, thermal conductivity λ = 0.6 W/(mK), specific heat c = 4190 J/(kgK), kinematic viscosity $\nu = 10^{-6}$ m^2/s. The water velocity and the temperature at the channel inlet are equal to v_{in} = 0.01 m/s and T_{in} = 20°C, respectively, the temperature of the walls is equal to T_w = 60°C [6] and is the same as the obstacle temperature. The initial conditions $u = v = 0$ and $T = T_{in}$ are also given.

It is assumed that $m = 20$, $n = 80$, which means that grid step $h = k = 0.005$ m. Additionally, $m_1 = 9$, $n_1 = 21$, $n_2 = 31$. The time step is equal to $\Delta t = 0.01$ s.

In Figures 3 and 4, the streamlines obtained using the authorial computer program and ANSYS software, respectively, after 6 s are shown. Figures 5 and 6 illustrate the temperature distribution after 6 s. It is visible that both of the streamlines as well as the temperature distributions are similar. Computations were also made for two other obstacle dimensions, namely $H = 0.06$ m and $W = 0.1$ m (wide obstacle) and $H = 0.08$ m and $W = 0.02$ m (high obstacle). The results are shown in Figures 7-10. It is also decided to perform another analysis, where the obstacle is shifted, this means the new value of parameter $l = 0.18$ m is assumed. The dimensions of the obstacles are the same, as previously illustrated. The temperature distributions are shown in Figures 11-13.

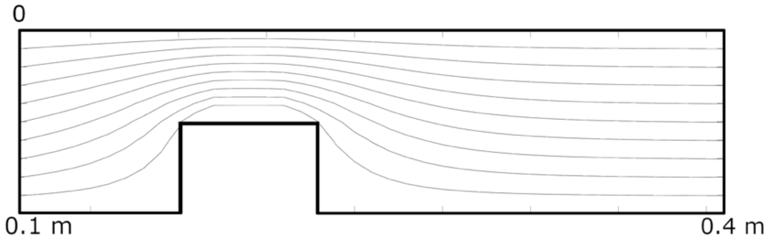

Fig. 3. Streamlines after 6 s - normal obstacle

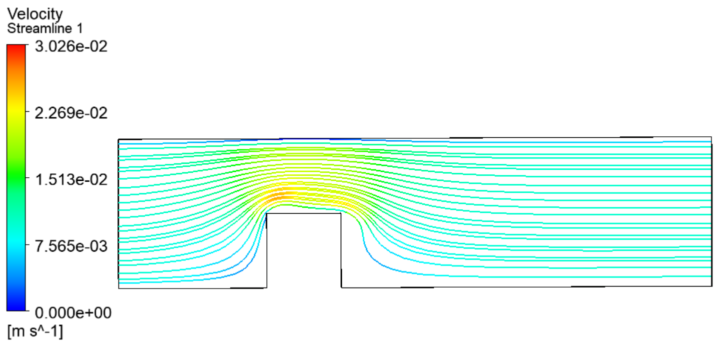

Fig. 4. Streamlines after 6 s (ANSYS) - normal obstacle

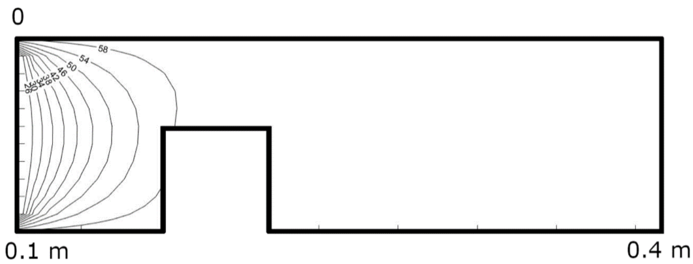

Fig. 5. Temperature distribution after 6 s - normal obstacle

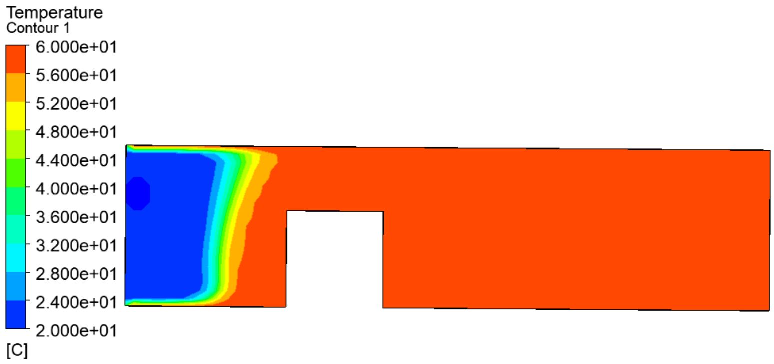

Fig. 6. Temperature distribution after 6 s (ANSYS) - normal obstacle

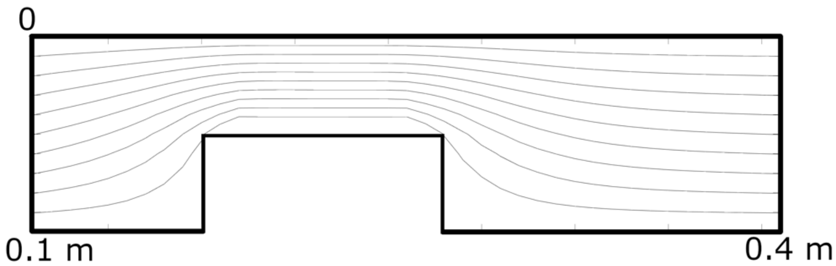

Fig. 7. Streamlines after 6 s - wide obstacle

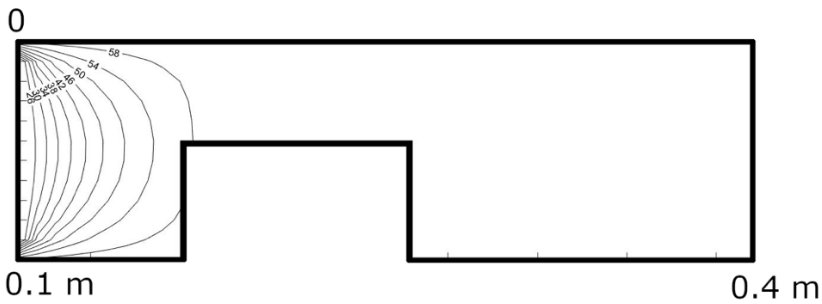

Fig. 8. Temperature distribution after 6 s - wide obstacle

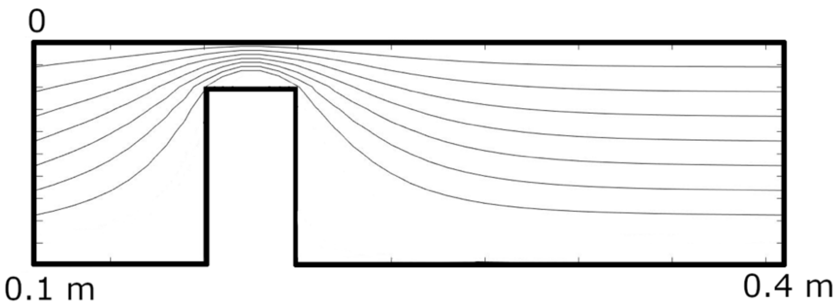

Fig. 9. Streamlines after 6 s - high obstacle

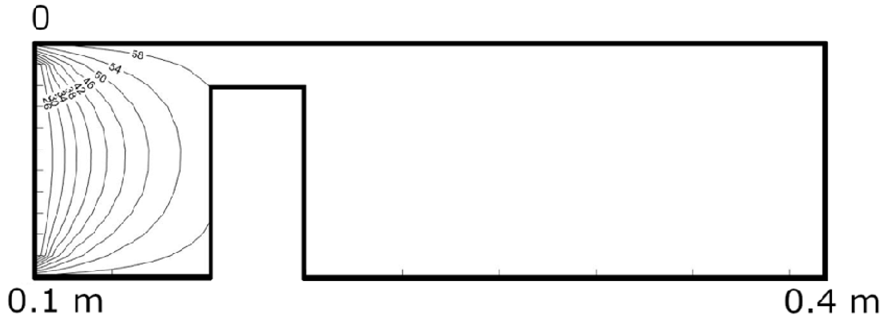

Fig. 10. Temperature distribution after 6 s - high obstacle

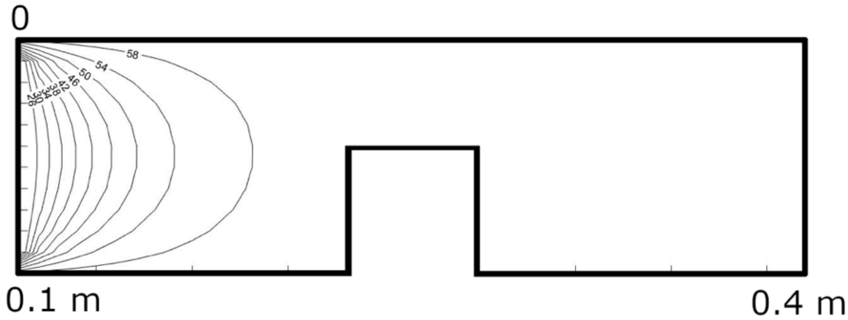

Fig. 11. Temperature distribution after 6 s - shifted obstacle

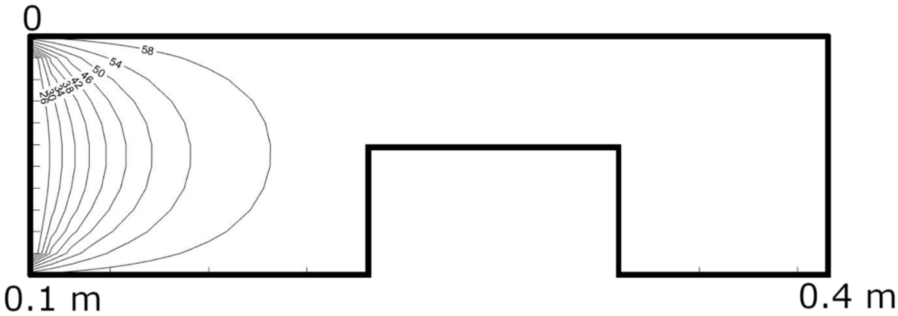

Fig. 12. Temperature distribution after 6 s - shifted wide obstacle

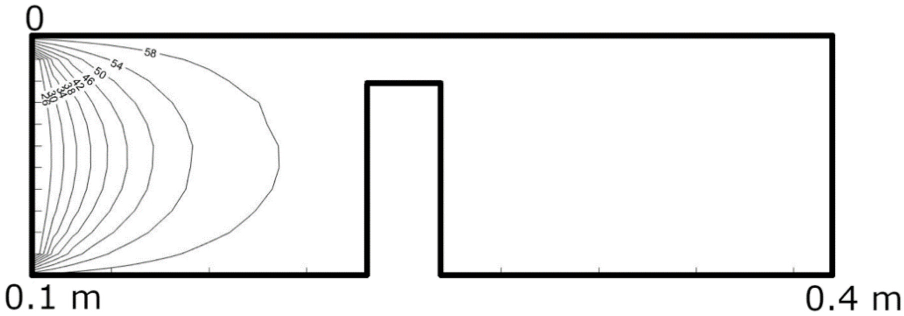

Fig. 13. Temperature distribution after 6 s - shifted high obstacle

The computations carried out show that after 6 seconds the steady-state temperature distribution is obtained. For all variants of obstacle dimensions and location, only before the obstacle the temperature changed from 20 to 58°C. In the remaining sub-domain, the temperature is 60°C and is equal to the obstacle temperature.

5. Conclusions

In this study, the coupled analysis of fluid flow and heat transfer in a rectangular channel with an obstacle has been presented. The different variants of obstacle dimensions and location have been taken into account. The problem has been solved using the finite difference method and authorial computer program. The results have been compared with the results obtained using the ANSYS Fluent software.

For the assumed dimensions of a rectangular channel with an obstacle, after 6 seconds the steady state has been achieved. Regardless of the size and location of the obstacle, after this time the temperature behind the obstacle reached a temperature equal to the temperature of the obstacle.

The authorial computer program allows, among other, to analyze the fluid flow and heat transfer in rectangular channel with more obstacles. It should be noted that the constant temperature of obstacle has been assumed here, but in future the temperature distribution in the obstacle will also be determined.

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