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Influence of Separated currents on heat Transfer in a discrete rough channel.

In this paper was made numerical simulation of flow of the current in the round smooth channel, and in the channel with a discrete roughness. Also, was reviewed the influence of separated currents on index of the heat transfer. The results of numerical analysis have shown that the intensity of the heat exchange in the channel with discrete roughness increases by 20% in comparison to the smooth channel.

Introduction.

Typical examples of highly effective heat exchange surfaces could be found in airplanes, spacecrafts and its power - plants. These technological industries set high standards on efficiency of heat exchange devices in terms of reduction of its mass, volume, shape optimization and cost cutting.

To improve energy performance are being developed and are put into exploitation set of special-purpose hardware, such as heat exchange devices, which allow to use an existing energy with a various degree of efficiency.

The intensification of the heat exchange in channels with the artificially created discrete roughness of the wall is the most promising approach for industrial purposes.

Tough the question regarding the intensification and efficiency of this method remains open, as too little is known regarding the mechanism of these processes and its possible changes; therefore, special skills to provide reliable calculation of the heat exchange are critical for the engineering of power devices.

The goal of this paper is to review the influence of separated currents on the heat exchange in the channel with discrete a roughness executed in the form of semi spherical depressions (dimples).

Solution of the examined problem.

Computer simulation was performed using the selected package of CAD/CFD programs SolidWorks/FlowSimulation. The complete system of Navier-Stokes equations and the energy equation were solved using the k-ε model of turbulence.

In the CAD program SolidWorks, three-dimensional computing models of smooth and discretely roughed pipes were constructed with the following geometric characteristics: inner pipe diameter d_b = 0.018 m, external diameter d_{out} = 0.022 m, length L = 1.6 m.

As a discretely rough surface in the pipe were chosen spherical depressions (dimples) with sharp entrance and exit edges, which were located in the in-line order with a relative width between the dimple axes S/h = 10 and the angle φ = 120 ° of dimple position. Fig. 1.

The following were accepted as the boundary conditions: at the pipe inlet – flow rate within the V_{inlet} = 0.3 -1 m/s at fluid temperature t_{inlet} = 20°C. The initial Reynolds number - Re_{inlet}= 5000-18000. The channel walls have physical properties of aluminum and are heated up to the temperature t_{wall}=105°C. Fluid flow is turbulent.

The efficiency of the heat-exchange surface was evaluated using the indexes of the heat transfer.

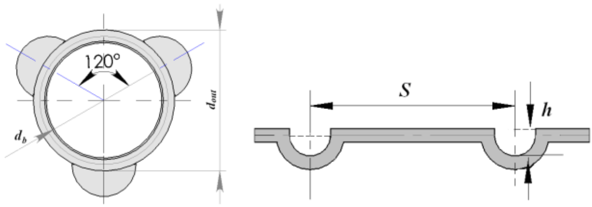

Fig.1. Geometric model with discretely rough surface.

For the numerical solution of the question was used the initial system of nonstationary Navier-Stokes equations with complementary equations describing the turbulent transfer, which are discretized in both space in the computational area and time. As a result, the entire computational area is covered by a computational grid. The size and the number of its cells could be determined by the user or automatically.

The finite volume method is used to discretize the differential equations and solve the resulting system of algebraic equations in the FlowSimulation program.
To gain the satisfactory accuracy of the solution results in this paper were required about 1,000,000 to 1,200,000 liquid and solid elements depending on the type of the problem.

Results and discussion.

It was necessary to resolve several questions to achieve this goal.
At the first stage was performed numerical calculation of heat exchange in the smooth and is discrete-rough channel. The efficiency of the heat-exchange surface was evaluated by the indexes of the convective heat exchange at certain points, were values were averaged. The points were located on the horizontal axis along the pipe diameter with 0.5 mm spacing and at 1.5 m distance from the inlet section (on a smooth site of the channel).

Validity check of the solution to the question under review was performed by comparison of theoretical solution [1,2,3] to the results of numerical experiment with use of dependencies (1, 2).

$$Nu_{1,2} = 0{,}021 \cdot \mathrm{Re}_{water}^{0,8} \cdot \mathrm{Pr}_{water}^{0,43} \cdot \left(\frac{\mathrm{Pr}_{water}}{\mathrm{Pr}_{wall}} \right)^{0,25} \cdot \varepsilon_{1,2} \qquad (1)$$

where, Nu_1 – heat transfer index for a smooth channel, Nu_2 – heat transfer index for a discretely rough channel, Pr – Prandtl number, indexes fluid and wall.
ε_1 – correction for the initial flow area in the smooth pipe, which value is equal to 1 at L/d >50. ε_2 – correction considering the growth in the heat transfer coefficient in consequence of artificial roughness:

$$\varepsilon_2 = 1{,}04 \cdot \mathrm{Pr}_{water}^{0,04} \cdot \exp\left[0.85 \cdot f \frac{(s/h)_{opt}}{s/h} \right] \qquad (2)$$

$$\left(\frac{s}{h}\right) \le \left(\frac{s}{h}\right)_{opt} \qquad f\left(\frac{s}{h}\right) = \left(\frac{s/h}{(s/h)_{opt}} \right)$$

where s – distance between axes of dimples, h – inner radius of dimple (Fig. 1), $(s/h)_{opt}=13\pm1$

Comparison between the results of theoretical solution and numerical calculation for a smooth channel has demonstrated a satisfactory matching, which was not exceeding the allowable range 5-10% .

The obtained result showed that the heat transfer index Nu in the discretely rough channel under review will double comparing to the heat transfer index Nu in smooth pipe [3].

At the second stage were reviewed the features of the flow in a dimples of a discretely rough channel.

Based on the results of numerical calculation was considered movement of a fluid in longitudinal section in discretely rough channel’s area in the location of depressions.

The flow of liquid moves along a smooth channel with a constant velocity V, fig.3 a. Reaching the inlet edge of the depressions, the flow moves without changing direction of its motion. And when the fluid flow reaches the outlet edge of the dimple, it turns back around dimple, forming the so-called vortex. Then it turns back to the outlet edge, while still retaining its full energy.

It is important to note, that at slowdown of returnable flow along a wall dimple the liquid heats up, before this current will get in the area of the mixed flows.

The obtained result of numerical simulation does not contradict the experimental studies carried out in the publications [4].

A more complex vortex flow is observed in the crosscut section of the channel under review fig.3 b. Reaching the inlet edges, the flow of liquid turns back, envelope the dimple and thereby forms two vortices. Then, part of the flow goes to the mixing area of the streams, and part of it returns to the smooth channel wall, forming additional two small vortices. Graphical images of current’s flow in the channel’s dimple – in longitudinal and crosscut sections with initial flow’s velocity Vinlet =0,9 m/s are shown on Fig. 3a,b.

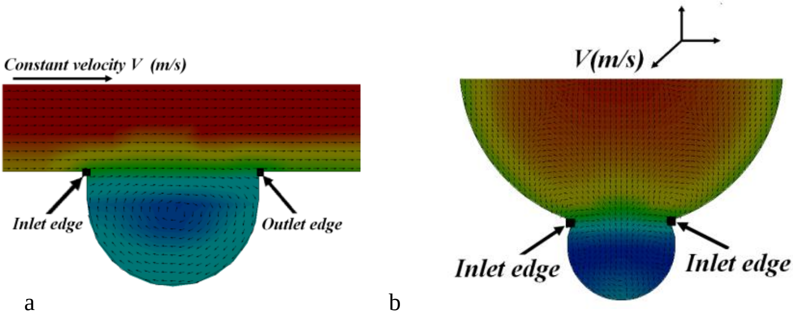

Fig. 3. Images of the dimple being enveloped by flow in the longitudinal section: a) V_{inlet} = 0.9 m/s; in the crosscut section: b) V_{inlet} = 0,9 m/s.

The readings were taken at set points, along the radius of the straight channel and the dimple. As a result, velocity decreasing in the bottom of the dimple (near the wall). When current receding from the walls its velocity suddenly increases, and upon approaching the center of the vortex, the velocity decreases. When moving further from the center of a vortex in dimple's outlet direction, sudden increase fluid flow velocity is observed once again. However near to the channel axis, the flow velocity is not affected by significant changes fig.4. With an increase in the flow velocity in a channel with a discrete roughness in comparison to a smooth one, the Nusselt number increases for more than 20%. The results of the calculation are shown in Fig. 4.

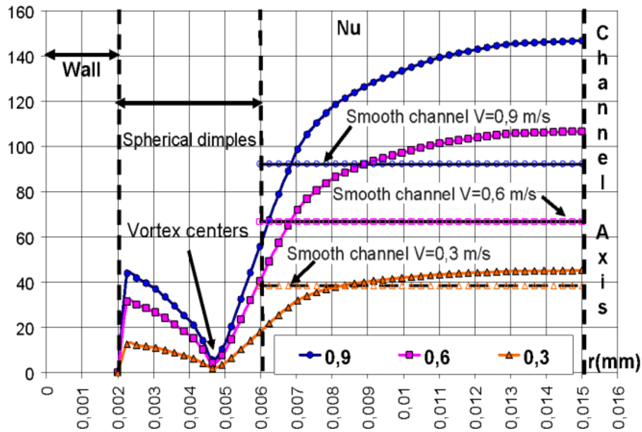

Fig.4. Graph of dependency of Nusselt number versus channel radius. Circle- V_{inlet} = 0,9 m/s, square - V_{inlet} = 0,6 m/s, triangle -V_{inlet} = 0,6 m/s. Straight lines are the average Nusselt number in a smooth channel for the flow velocities under review.

At the fourth stage was reviewed the impact of the smooth channel's wall located next to the dimple. The results of numerical calculation showed that heat exchange in the area of the smooth wall is less intensive than in the area of the dimple. This caused by the fact that the zone of intensive mixing of the liquid's layers in the area of the dimple occurs only up to the horizontal axis of the channel.

Conclusion.

In this paper was conducted numerical simulation of hydrodynamics and heat exchange in the round smooth channel with the discrete roughness made in the form of semi spherical dimples. Based on the obtained calculations results was reviewed the specifics of the flow in single dimple in crosscut and longitudinal sections of the channel. It is notable, that the intensity of heat transfer depends on the return currents formed in the dimples. It is shown, that intensity of heat exchange in the is discrete-rough channel increases by 20 %, in comparison to the smooth channel.

References

1. Д.Н. Попов, С.С. Панаиотти, М.В. Рябинин Гидромеханика, Москва, Издательство МГТУ им.Н.Э. Баумана, 2002, 383 стр.
2. Гомелуари В.И. Влияние искуственной шероховатости на конвективный теплообмен. «Труды Института физики АН ГССР», Тбилиси, 1963, т.9,с 111-145.
3. Sidenko N., Dzelzitis E. The method of numerical modeling of hydrodynamics and heat exchange in a channel with discrete roughness// International Scientific Journal „Mathematical Modeling" year II, 2018, 61-65 pp.
4. Chang P. Separation of Flow //New York, Pergamon Press, 1971.

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