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Hydraulic resistance of an annular channel with a rectangular roughness on the wall

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Abstract. This paper provides a brief overview of approaches to calculating the hydraulic resistance coefficient of a channel with rough walls and describes their advantages and disadvantages. One of the most popular engineering approaches is based on integral characteristics. By the influence of roughness, the logarithmic velocity profile changes, which is fully described by the second constant. It determines the interaction of a turbulent flow with a rough wall. Its numerical value depends on a large number of factors, such as geometry of the roughness protrusion, the dimensionless height of the protrusion, its shape, angle of attack, and so on. Getting a generalized dependence of this kind is an actual task of rough channel hydraulics. In this paper, the second constant of the logarithmic velocity profile is numerically calculated using turbulence models. A symmetric model of a developed turbulent flow in an annular channel with a rectangular roughness on the wall is implemented. Roughness was applied to the surface of the rod, the inner surface of the pipe was smooth. The result of numerical simulation was the obtained velocity profile, which was used to determine the numerical value of the second constant. The obtained results are satisfactory agreement with the experimental data.

1. Introduction

Heat exchange intensifiers in the form of transverse artificially created protrusions can increase the efficiency of reactor cores, including the VVER – 1000 type [1,2], steam turbines of nuclear power plants and thermal power plants, heat generation systems of steam turbines of nuclear power plants and thermal power plants, aviation gas turbine engines, and so on. One of the methods of heat transfer intensification is the use of rough surfaces. There are several approaches to calculating the hydraulic resistance of rough channels.

One of the first is the equivalent sand roughness method presented in [4]. Equivalent sand roughness is understood as the size of sand grains, in which a round pipe with sand roughness has the same hydraulic resistance in the self-similar region as a pipe with a different type of roughness of interest to the designer [4,5]. Some methods for determining the numerical value of the equivalent sand roughness for a given artificial roughness are presented in [6-8]. This method has been widely used in practice for some time, but it has two major disadvantages. The first disadvantage is low information content. The value of the equivalent sand roughness does not provide information about the size, pitch, density of the protrusions and their effect on hydraulic resistance. The second disadvantage is that the method is not applicable to calculating the coefficient of hydraulic resistance in the transient flow mode. These disadvantages have contributed to the development of other calculated models.

Calculation methods using integral turbulence models are simple and fundamental. In practice they are more widely used than direct numerical modeling. Integral equations are supplemented by semi-empirical or empirical laws of resistance or heat transfer [9,10]. The fundamental law is the Prandtl hypothesis [11,12]. The solution of the problem often has the form of a generalizing relation. The accuracy of this solution may be close to numerical methods. The disadvantage of integral methods is the incompleteness of ideas about turbulent heat transfer.

In [13,14], an engineering technique based on the analysis of the local hydrodynamic pattern illustrated in figure 1 is proposed. This technique is described in detail in the works.

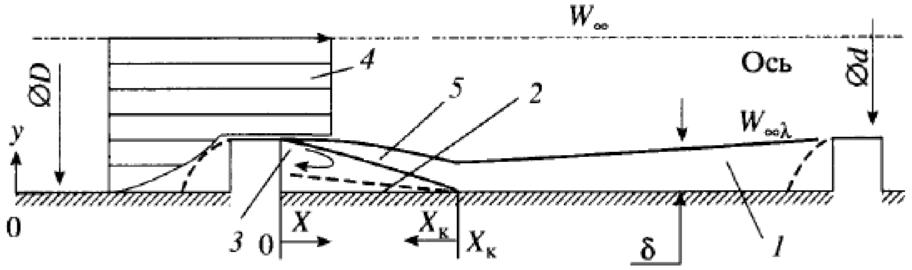

Figure 1. Diagram of the hydrodynamic pattern near the rough wall [15]; 1 – internal boundary layer; 2 –boundary layer formed on the channel wall immediately behind the ledge; 3 - cavern; 4 – incoming flow; 5 - boundary layer.

The proposed approach is fraught with considerable difficulties. Length of recirculation area behind the ledge, a small recirculation area in front of the ledge, boundary layer in cavern is areas requiring detailed descriptions. It is necessary to know the relationship of the shape and size of the roughness with the parameters of the forming areas in order to obtain the correct dependences of heat transfer and resistance of these channels. In other words, the description of all flow zones between two protrusions for all possible variants of their shape and geometry seems to be a complex research process associated with many years of theoretical and experimental efforts of more than one scientific group [16].

The next approach is an engineering technique based on integral characteristics. Here, the influence of protrusions on the flow is considered on average along the length of the channel. The speed profile changes under the influence of roughness. The logarithmic profile applied in the boundary layer undergoes changes that are fully reflected by the second constant

$$\Phi\left(\frac{\Delta V_*}{\nu}\right)=\frac{\bar{u}}{V_*}-\frac{1}{\kappa}\ln\frac{y}{\Delta} \tag{1}$$

where Δ - height size of roughness protrusions, V_* - dynamic velocity, ν – kinematic viscosity, $\bar{u}$ - average flow velocity, $\kappa = 0{,}4$ – the Karman constant [17-20], Δ - height size of roughness protrusions, y – distance from the wall.

The value of $\Phi\left(\frac{\Delta V_*}{\nu}\right)$ from equation (1) determines the shift of the velocity profile and depends on the roughness mode and its geometry, but does not depend on the shape of the channel [12,20,21,24]. The dependence $\Phi\left(\frac{\Delta V_*}{\nu}\right)$ can be determined by measuring the velocity profile in a rough channel or by measuring the pressure drop in the channel using the Darcy-Weisbach formula, taking into account the important ratio $\frac{\bar{u}}{V_*}=\sqrt{\frac{\lambda}{8}}$. In [22], an assumption that generalizes geometrically inappropriate roughness is made. It consists in the number of necessary parameters for the general description of the universal speed profile (2).

$$\Phi = f\left(h^{+}; {}^{s}\!/_{k}; \varphi; shape\right) \tag{2}$$

where φ – angle of attack of the protrusion by the flow, «shape» - the shape of the roughness protrusion. Knowledge of the functional dependence of this kind will allow calculating the coefficient of hydraulic resistance of a channel with rough walls with sufficient accuracy in all modes of the coolant flow.

In this paper, we analyzed the applicability of integral turbulence models to hydraulic calculations of channels with rectangular roughness on the wall, in order to apply them to obtain a generalized dependence of the form (2).

2. Hydraulic calculation

Experimental data on the coefficient of hydraulic resistance λ and the value of $\Phi\left(\frac{\Delta V_*}{\nu}\right)$ of an annular channel with rough walls are published in [23]. The circular channel was a smooth tube with a rod fixed in it. A rectangular roughness is applied to the rod. Ledge height $\Delta = 0{,}12$ mm, ledge pitch $s = 1{,}0$ mm, ledge width $b = 0{,}2$ mm.

Using the ANSYS FLUENT 19r1 software, a symmetric model of a fully developed turbulent incompressible flow in an annular channel is implemented. The model is shown in figure 2. The calculation of changes in the axial, radial velocity and surface friction coefficient along the length of the pipe at different values of the Reynolds numbers is performed. The simulation is based on the Reynolds and Navier-Stokes equations. These equations were closed by the equations of the k-ε turbulence model and two parametric models: standard and SST. It should also be noted that boundary layers in turbulent flows require a fine mesh size near the walls. It depends on the choice of turbulence model. The results of numerical simulation are shown in figure 3 and table 1.

Table 1. Comparison of experimental data with the calculation.

Re	λ_{CFD}	λ_{exp}	Φ_{CFD}	Φ_{exp}
5920	0.0387	0.0388	8.37	8.98
7360	0.0376	0.0363	8.89	8.9
10800	0.0369	0.0348	8.06	8.8
12950	0.03528	0.0344	7.62	8.6
15640	0.03455	0.0339	7.23	7.9
25550	0.033	0.033	6.44	7.2

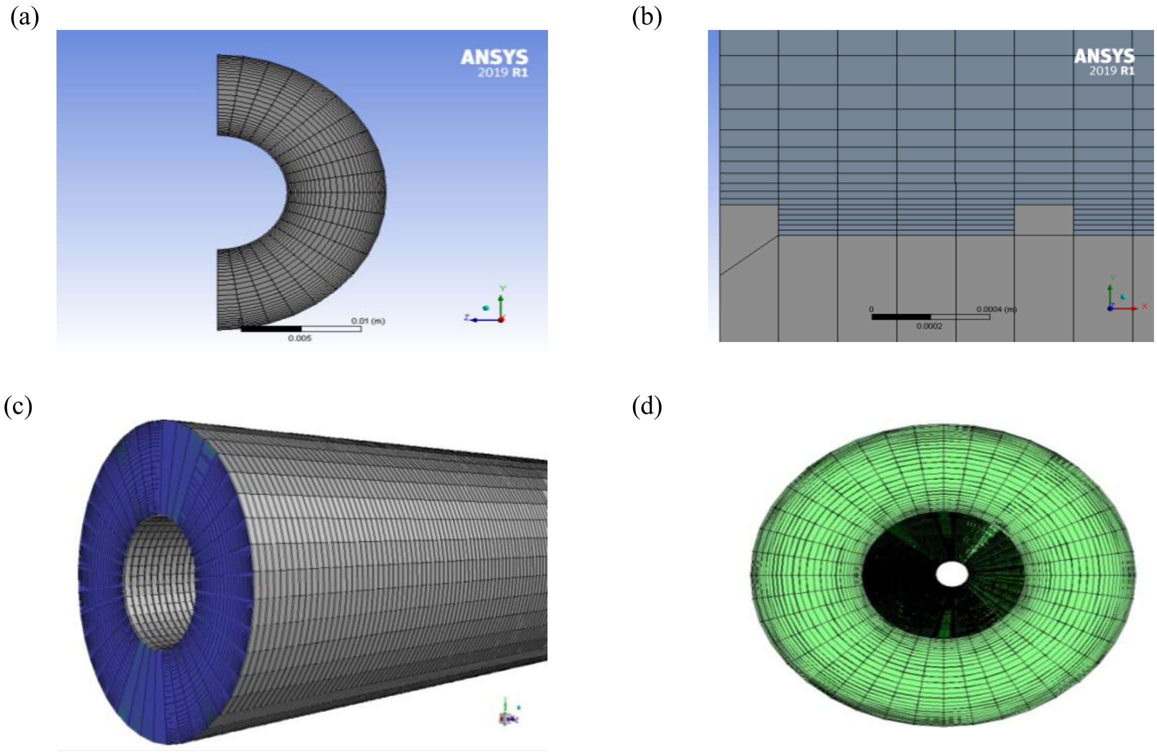

Figure 2. Calculation grid.

In table 1 λ_{CFD} – the coefficient of hydraulic resistance calculated from the model, λ_{exp} – the coefficient of hydraulic resistance from the experiment [23], Φ_{CFD} – the constant of the logarithmic law calculated from the model, Φ_{exp} – the constant of the logarithmic law from the experiment [23].

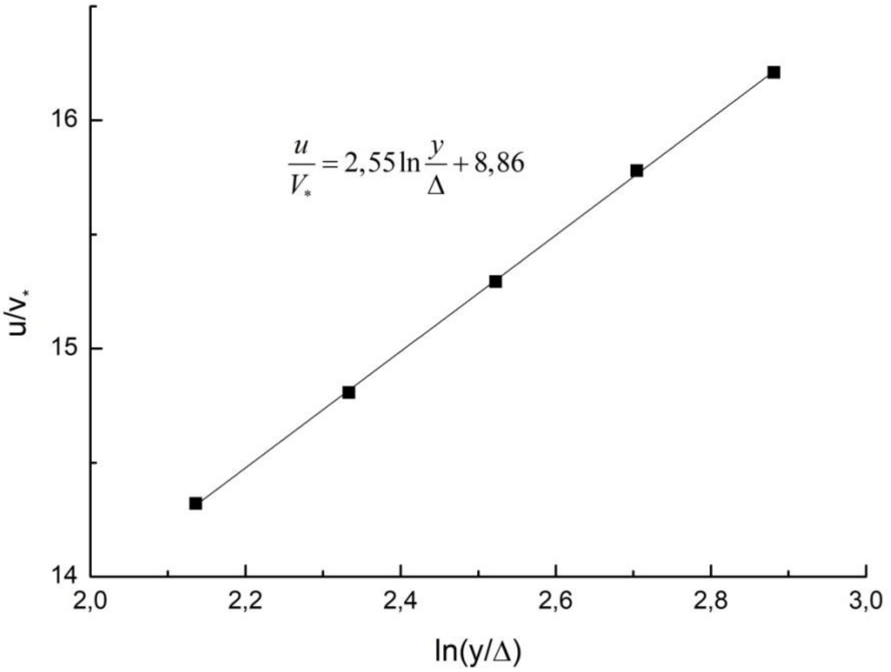

Figure 3. Logarithmic velocity profile at Re = 5920.

3. Conclusion

Integral turbulence models can be successfully applied in calculations of the second constant of the universal velocity profile and the coefficient of hydraulic resistance of a channel with a rectangular roughness on the wall.

References

[1] Olympiev V V 1992 Thermohydraulic calculation of flow around rough fuel elements, efficiency of their application in the VVER-1000 Reactor *J. Heat power engineering*. **3** p 48

[2] Olympiev V V 1993 Efficiency of heat exchange intensification by means of fuel element roughness in the VVER - 1000 reactor *J. Heat power engineering* **3** p 35

[3] Leontiev A I et al 2007 The effect of intensifiers of heat transfer on the thermohydraulic properties of channels *Thermophysics of high temperatures* **45(6)** pp 925-953.

[4] Schlichting G 1965 The theory of the boundary layer p 711

[5] Petukhov BS, Genin LG and Kovalev SA 1986 Heat exchange in nuclear power plants *Energoatomizdat* pp 224-234

[6] Mikhailov V V 2012 On the possibilities of calculating the equivalent sand surface roughness for flows in pipes and the boundary layer *Scientific notes of TSAGI* **43(1)** pp 80-86

[7] Zagoskin V I Hydraulic method for determining equivalent sand roughness AS SU 1377576

[8] Korsun A S, Pisarevskii M I, Fedoseev V N and Delov M I 2017 Determining the equivalent sand roughness of a surface by measuring the hydraulic resistance of an annular channel. *Power Technology and Engineering* **51(2)** pp 151-155

[9] Fedyaevsky K K, Ginevsky A S 1973 Calculation of the turbulent boundary layer of an incompressible liquid *Leningrad: Sudostroenie* p 252

[10] Kutateladze S S, Leontiev A I 1985 Heat and mass Transfer and friction in a turbulent boundary layer *Moscow: Energoatomizdat* p 318

[11] Mitrofanova O V 2010 Hydrodynamics and heat exchange of swirling flows in the channels of nuclear power plants *M.: FIZMATLIT* p 288

[12] Zhukauskas A A 1982 Convective transfer in heat exchangers *M .: Nauka* p 472

[13] Olympiev V V 1991 The calculation of heat transfer and hydrocortisone turbulent flow in discrete rough channels. Izv. universities. Aviation equipment. **4** p 69

[14] Tarasevich S E, Zlobin A V and Yakovlev A B 2015 Hydrodynamics and heat transfer during the movement of a single-phase liquid in pipes with artificial roughness *High temperature Thermophysics* **53(6)** p 938-2

[15] Leontiev A I, Olympiev V V 2007 Influence of heat transfer intensifiers on the thermohydraulic properties of channels *High temperature Thermophysics* **45(6)** pp 925-953

[16] Reynolds A J 1979 Turbulent flows in engineering applications *Moscow: Energia* p 408

[17] Vysotsky L I 2015 On the Karman constant part 1 *Izvestiya vuzov. Construction* **6** pp 81-89

[18] Vysotsky L I 2015 On the Karman constant part 2 *Izvestiya vuzov. Construction* **7** pp 94-100

[19] Millionshchikov M D, Subbotin V I, Ibragimov M H et al 1973 A study of velocity fields and coefficients of hydraulic resistance in pipes with an artificial roughness of the walls *FEI* – 385

[20] Vysotsky L I 2013 On the issue of self-similarity of flows in longitudinally homogeneous turbulent flows. *Scientific journal of the Russian research Institute of land reclamation problems* **2(10)**

[21] Kader B A, Yaglom A M 1984 Effect of roughness and longitudinal pressure gradient on turbulent boundary layers *Results of science and technology VINITI. Ser. Fluid and gas mechanics* **18** pp 3 - 111

[22] Chandra P R, Khan J K, and Lau S K 1989 Influence of the fin angle on the distribution of local heat and mass transfer coefficients in a two - way channel with a ribbed roughness *Modern*

mechanical engineering **4** p 117

[23] Vilemas Yu, Shimonis V, Adomaitis I E 1989 Intensification of heat exchange in gas-cooled channels *Monograph, ed. Prof. And Zhukauskas* pp 138-139

[24] Korsun A S, Pisarevsky M I, Fedoseev V N and Kreps M V 2017 Velocity distribution in a turbulent flow near a rough wall *IOP Conf. Series: Journal of Physics: Conf. Series* **891** 012065