Determination of the turbulence integral model parameters for a case of a coolant angular flow in regular rod-bundle

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Abstract. Research results of "k-ε" turbulence integral model (TIM) parameters dependence on the angle of a coolant flow in regular smooth cylindrical rod-bundle are presented. TIM is intended for the definition of efficient impulse and heat transport coefficients in the averaged equations of a heat and mass transfer in the regular rod structures in an anisotropic porous media approximation. The TIM equations are received by volume-averaging of the "k-ε" turbulence model equations on periodic cell of rod-bundle. The water flow across rod-bundle under angles from 15 to 75 degrees was simulated by means of an ANSYS CFX code. Dependence of the TIM parameters on flow angle was as a result received.

1. Introduction

The efficient transport coefficients of an impulse and heat necessary for closure of the averaged equations of a heat and mass transfer in the rod-bundles in an approximation of an anisotropic porous media can be expressed through effective turbulent viscosity of a coolant flow which can be determined by TIM [1].

The TIM equations were received by volume-averaging of the "k-ε" turbulence equations on rod-bundle periodic cell. The efficient transport coefficients of turbulent kinetic energy and its dissipation rate and the turbulence generation terms entering these equations are functions of geometrical parameters of rod-bundle and parameters of coolant flow [1].

The type of these functions was established during the averaging procedure, and values of coefficients in them can be received by means of numerical simulation of a coolant flow across rod-bundle by the ANSYS CFX code. The longitudinal and transversal coolant flow across rod-bundles was considered earlier [2, 3]. In these researches the size of a constant of proportionality $C_v$ in the expression connecting effective turbulent viscosity $\nu_t^{\text{cell}}$ of coolant flow with a turbulent kinetic energy $k$ and its dissipation rate $\varepsilon$ was defined:

$$\nu_t^{\text{cell}} = C_v \frac{k^2}{\varepsilon}. \quad (1)$$

The value of this coefficient in "k-ε" turbulence model is set and is a constant [4]. In TIM the value $C_v$ is determined from a formula (1) by the volume-averaged values of a turbulent kinetic energy, its dissipation rate and effective turbulent viscosity, received during simulation of a stationary coolant flow by means of the ANSYS CFX code.
For a transversal flow the coefficient $C_v$ can be considered as a constant which value differs from its used in "$k$-$\varepsilon$" turbulent model [4]. For a longitudinal flow this coefficient in TIM is function of Reynolds number $Re$.

2. Problem definition

The objective of this work is definition of dependence of coefficient $C_v$ on a angle of a coolant flow across the regular smooth cylindrical rod-bundle. The made theoretical analysis of anisotropic properties of such structures showed that in case of an angular flow the coefficient of $C_v$ has to be a function from a square of a cosine of the angle between coolant flow direction and the rod direction in a bundle:

$$C_v = C_v \uparrow \cdot f_1(\beta) + C_v \perp \cdot f_2(\beta),$$  \hspace{1cm} (2)

where $C_v \uparrow, C_v \perp$ - coefficients at a longitudinal and transversal coolant flow across rod-bundle; $f_1, f_2$ – is unknown functions from value $\beta = \cos^2(\varphi)$; $\varphi$ – a angle between coolant flow direction and rod direction in a bundle.

For the limiting cases of transversal ($\beta = 0$) and longitudinal ($\beta = 1$) flow functions $f_1(\beta), f_2(\beta)$ have to provide value of coefficient $C_v$ equal $C_v \perp, C_v \uparrow$, respectively. Therefore for $C_v$ the following angular dependence was offered:

$$C_v = \beta \cdot C_v \uparrow + (1-\beta) \cdot C_v \perp.$$  \hspace{1cm} (3)

The check of a formula (3) was also the work goal.

3. Calculation results

Within the research it is supposed to make a series of numerical experiments for a stationary water flow at ambient temperature across rod-bundle for various Reynolds numbers and angles of a flow. Besides, it is supposed to consider rod-bundles both with corridor and triangular packing.

At this stage of work the water flow at ambient temperature across rod-bundle with triangular packing under various angles in the range from 15 to 75 degrees (15, 30, 45, 60, 75 degrees) was investigated. Porosity of the considered bundle made 0.55. Input flow velocity in all considered bundles was a constant and corresponded to a Reynolds number $1.81 \cdot 10^4$.

For each of the considered flow modes across rod-bundle it was received stationary distributions of velocity, pressure, kinetic energy of turbulent pulsations, its dissipation rate and kinematic turbulent viscosity coefficient. The mean values of a kinetic turbulent energy, its dissipation rate and coefficient of kinematic turbulent viscosity received by the subsequent averaging on a periodical cell were used for coefficient $C_v$ definition from a formula (1).

The received dependence of coefficient $C_v$ on coolant flow angle is shown in the figure 1.

For check and correction of dependence (3) calculated values of coefficient $C_v$ shown in the figure 1 were presented in the form

$$C_v = C_{v2} \cdot f(\beta),$$  \hspace{1cm} (4)

where $C_{v2}$ - the coefficient value received on a formula (3), and $f(\beta)$ - the unknown correcting function of parameter $\beta$ which values for the limiting cases $\beta = 0, 1$ have to equal 1.
Figure 1. Calculated angular dependence of coefficient $C_\psi$

The correcting function $f(\beta)$ received is shown in the figure 2. In case of validity of formula (3) the value of this function has to be identically equal 1 at any angular flow. It is visible that approximation described by a formula (3) leads to a mistake about 20% on the most part of $\beta$ range. The maximal mistake makes about 30% for $\beta$ in the range of 0.7 - 0.8 that there correspond to flow angles $26^{\circ} - 33^{\circ}$.

Figure 2. The calculated correcting function dependence on $\beta$
Taking into account the requirements to function $f(\beta)$ properties stated above, the dependence shown in the figure 2 can be described by a polynomial of the second degree:

$$f(\beta) = 1 - C \cdot \beta \cdot (1 - \beta).$$

(5)

where $C = 1.164$.

4. Conclusion

The dependence on the angle of flow across the regular rod-bundle of a constant $C_r$ in a formula of definition of effective turbulent viscosity through energy of turbulence and speed of its dissipation was defined. It was shown that use of the offered earlier simplified angular dependence of this coefficient leads to 20 – 30% to understating of size of effective turbulent viscosity especially at small angles of a flow. Further correction of angular dependence requires carrying out further researches in the wide range of Reynolds numbers, porosity and structure of rod-bundle.

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References

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