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COMPARISONS THE NUMERICAL RESULTS OF THE TURBULENCE MODEL FOR THE PROBLEM OF ROTATING TUBES INSIDE A DYNAMIC HYDROCYCLONE

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Abstract: The article provides a comparative analysis of turbulence models by numerically simulating a swirling flow inside a rotatable pipe. To solve this problem, the Reynolds averaged non-stationary Navier-Stokes equations in a cylindrical coordinate system were used. To find the Reynolds voltage, the turbulence model was used the most popular semi-empirical turbulence model. Comparison is made between models of different approaches to turbulence SSG / LRR-RSM-w2012 and νt-92. The numerical results obtained on the basis of turbulence models are compared with the well-known experimental results of Reich and Beer (1989).

Keywords: swirling flows, Reynolds averaged Navier-Stokes equations, model SSG / LRR-RSM-w2012, model νt-92.

Introduction. Known as a multiphase separator with high separation efficiency, small space requirement, and low energy consumption, hydrocyclone is gradually replacing the conventional vessel separator in the petroleum industry, and has been popularized to various fields [1]. However, the swirling flow in a conventional hydrocyclone is established by a tangential inlet, so the swirl intensity is closely related to the inlet pressure or flow rate. Thus the conventional hydrocyclone is handicapped by some inherent limits such as the necessity to have a high pressure inlet to get sufficient acceleration field and the loss of efficiency at low flow rate. Considering these drawbacks of conventional hydrocyclones, dynamic hydrocyclone (DH) was developed by TOTAL CFP and NEYRTEC [2]. The structure diagram of oil-water DH is shown in Figure 1, the main difference against static hydrocyclone is that fluid enters DH from an axial inlet, and is rotated by synchronous rotating blades and pipe (separation chamber wall) driven by a motor. Under the centrifugal force produced by swirling flow, lighter phase migrates towards the centerline then exits from overflow outlet and heavier phase moves towards the wall then exits from the underflow outlet. The performance of DH has been investigated by several researchers [3]. the results showed that DH can remove smaller oil droplets from water and can operates efficiently at lower inlet pressures compared with conventional hydrocyclones.

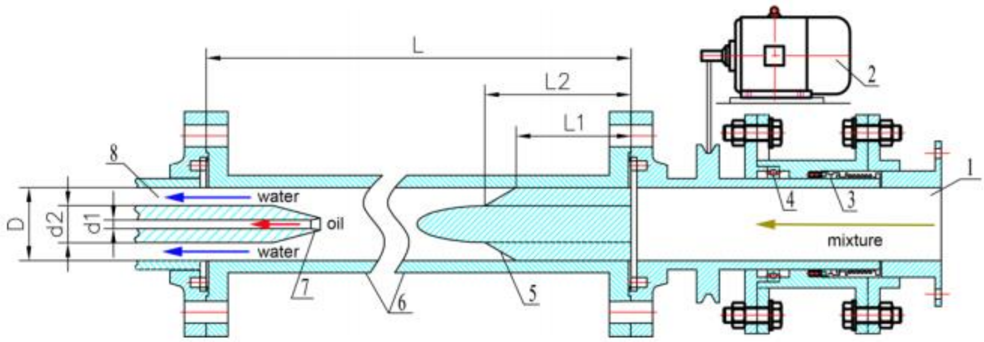

Fig. 1: Diagram of dynamic hydrocyclone.

1 - Inlet; 2 - Motor; 3 - Mechanical seal; 4 - Bearing; 5 - Blades; 6-Rotating pipe; 7 - Overflow outlet; 8 - Underflow outlet.

Statement of the problem. For numerical simulation of the turbulent flow of an incompressible fluid, the Reynolds equations were used [4]:

$$\begin{cases} \dfrac{\partial V_i}{\partial x_i} = 0, \\ \dfrac{\partial V_i}{\partial t} + V_j \dfrac{\partial V_i}{\partial x_i} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial x_i} = \dfrac{\partial}{\partial x_i}\left[\nu\left(\dfrac{\partial V_i}{\partial x_j} + \dfrac{\partial V_j}{\partial x_i}\right)\right] + \dfrac{\partial(-\overline{\vartheta_j \vartheta_i})}{\partial x_i}. \end{cases} \quad (1)$$

The system of Navier-Stokes equations averaged by Reynolds (1) is open. For closure in methods, the linear and nonlinear Boussinesq hypothesis is used.

Modeling turbulence. To describe the turbulent flow, the Reynolds-Averaged Navier-Stokes Equations (RANS) averaged according to the Reynolds equations are used. This system of equations is open, because It contains additional unknown components, the so-called Reynolds stresses. Therefore, all models that are aimed at closing this system are called RANS turbulence models. There are two approaches to finding Reynolds stresses. The first approach is linear (the Bussensk hypothesis is used). A striking representative of such models can be considered the Secundov νt-92 model.

$$\frac{\partial \rho \nu_t}{\partial t} + \frac{\partial(\rho u_j \nu_t)}{\partial x_j} = \rho(P_\nu - D_\nu) + \frac{\partial}{\partial x_j}\left[\rho(\nu + C_0 \nu_t)\frac{\partial \nu_t}{\partial x_j}\right] + \frac{\partial}{\partial x_j}\left[\rho(-\nu + (C_1 - C_0))\nu_t\right]\frac{\partial \nu_t}{\partial x_j}. (2)$$

The remaining functions and constants are presented in [5].

This model uses one equation for turbulent viscosity. Therefore, it is called a one-parameter model. The second nonlinear approach. A typical representative of the nonlinear RANS model is the various Reynolds stress models. The representative from this class of models is the SSG / LRR-RSM model. This is a Reynolds stress model with a second moment of mixed SSG / LRR that uses the ω equation for a length scale equation. The second moment Reynolds calculates each of the 6 Reynolds stresses directly (the Reynolds stress tensor is symmetric, so there are 6 independent terms).

Each Reynolds stress has its own transport equation. There is also a seventh transfer equation for the scale variable. This model is currently mainly used where conventional RANS models are not able to describe complex anisotropic turbulent flows.

$$\begin{cases} \frac{\partial R_{ij}}{\partial t} + \frac{\partial U_k R_{ij}}{\partial x_k} = P_{ij} + \Pi_{ij} - \varepsilon_{ij} + D_{ij}, \\ \frac{\partial \omega}{\partial t} + \frac{\partial U_k \omega}{\partial x_k} = \frac{a_\omega \omega}{k} \frac{P_{kk}}{2} - B_\omega \omega^2 + \frac{\partial}{\partial x_k}\left(\left(\mu + \sigma_\omega \frac{k}{\omega}\right)\frac{\partial \omega}{\partial x_k}\right) + \sigma_d \frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}. \end{cases} \quad (3)$$

The remaining terms and constants are presented in the article [6].

The aim of this work is to test and compare their numerical results with the linear RANS model νt-92 and the nonlinear SSG / LRR-RSM-w2012 model. To analyze

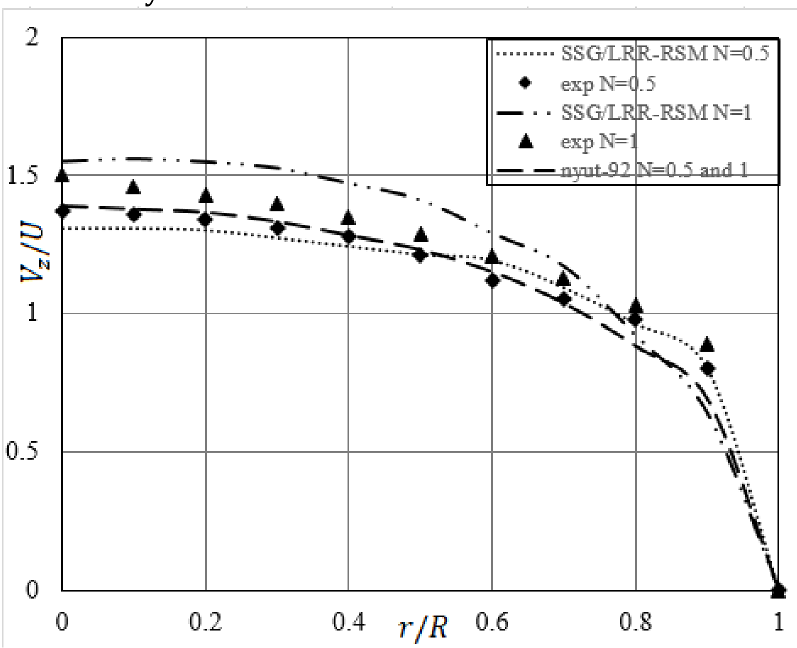

Fig. 2. Axial velocity profile in a rotating pipe

these models, the experimentally well-studied flow of a strongly swirling turbulent flow in a channel with sudden expansion is considered.

Study results. The numerical result was compared with experimental data [7]. In fig. 2-3, we compare the resulting axial and tangential velocity profiles.

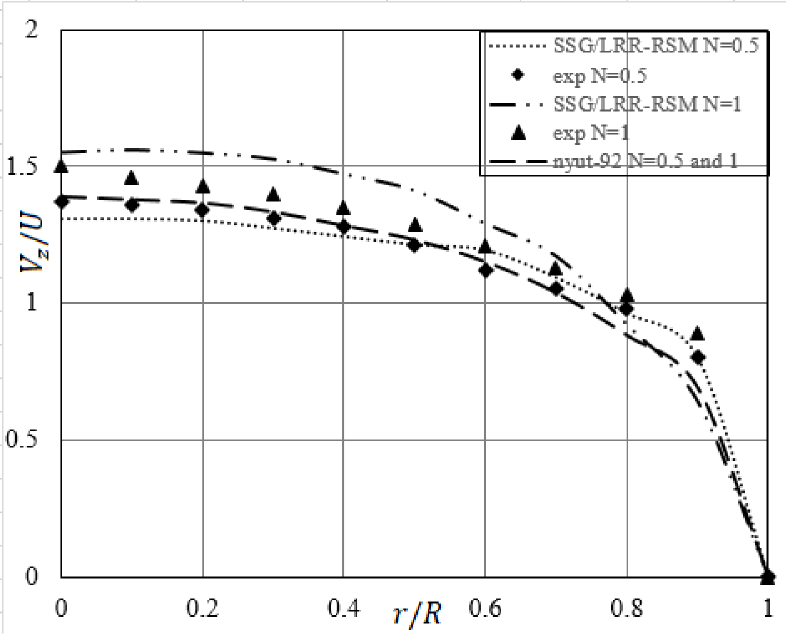

Fig. 3. Tangential velocity profile in a rotating pipe

Conclusions. The results obtained and their comparison with experimental data show that all the two approaches considered as a whole show good results. However, the closest results were obtained using the SSG / LRR-RSM model. The results for the νt-92 model are slightly worse. Therefore, given that it is a practical model, it can be recommended for use in engineering tasks where strong rotation of the flow occurs.

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