Numerical experiment optimization to obtain the characteristics of the centrifugal pump steps package

S V Boldyrev, A V Boldyrev
Kazan Federal University,
423800, 68/19 Mira avenue, Naberezhnye Chelny, Russia

E-mail: chelny@kpfu.ru

Abstract. The numerical simulation method of turbulent flow in a running space of the working-stage in a centrifugal pump using the periodicity conditions has been formulated. The proposed method allows calculating the characteristic indices of one pump step at a lower computing resources cost. The comparison of the pump characteristics' calculation results with pilot data has been conducted.

1. Introduction

Centrifugal pump characteristics are received experimentally on special stands [1; 2]. Moreover, several stages (figure 1) are used during testing compound pumps in order to exclude the effect of input and output devices on the results. Although, if there is quality measuring equipment, precise and quick at obtaining characteristics, its use in the design of new constructions leads to the costs brought about by the need of experimental samples refinement.

A numerical modeling of currents flowing in a running space of a pump can be considered to be an alternative way to locate pump characteristics in intermediate stages of design refinement to prototyping. However, its application requires [3; 4; 6; 7]: adequate mathematical model, optimal boundary conditions, quality computational grid with a sufficient number of cells, solver correct parameters. Therewith, the numerical experiment implies the licensed software and ample computational resources (to reduce time costs).

This work is devoted to assessing ways of numerical experiment optimization for the compound pumps.
2. Basic part

A numerical simulation of turbulent water flow has been performed in the running space of the compound centrifugal pump ETsNA(K)5A-80 in the licensed software package Star-CCM+ [8].

A mathematical model has been composed of Reynolds averaged Navier-Stokes equations and continuity (including stationary and rotating coordinate systems), equations of two-layer Realizable turbulence model $k - \varepsilon$ [5] with hybrid wall functions [9, 10].

Running space of a stage is conditionally divided into 3 areas (figure 2): an impeller (PK), a diffuser (HA), an intermediate area (formed by the outer surfaces of the impeller and a diffuser, besides by and inner surface of the pump casing). A computational grid (figure 2) consisting of many-sided cells, the size of which is chosen to be proportional to its square, is applied for the discretization of the areas. Near walls the grid is crushed with layers of prismatic cells so that the center of wall cells is within a buffer zone [9] of a boundary layer (recommended for the model of turbulence). The total number of control volumes in the grid has come up to 4.5 million.
There are several variants of boundary conditions in flow modelling within vane pumps [3; 8; 5; 6]:

1) If the input is set to the mass flow rate (corresponding to the flow at the selected point of characteristics) and the output is constant static pressure, in the simulation result is determined by the pressure at the inlet, whereby pressure pump is calculated. If the input is set to a constant total pressure, and the output is the static pressure (corresponding to the pressure at the selected point of

---

**Fig. 3.** Formulation of the problem (boundary conditions)

**Fig. 4.** Pressure characteristic of working-step in the centrifugal pump ETsNA(K)5A-80

**Fig. 5.** Energy characteristics of the working-stage in the centrifugal pump ETsNA(K)5A-80
characteristics), pump flow is determined.

2) Three-dimensional running space is treated either in whole or partially (to save computing resources), a part of running space being used around one blade inside each paddle wheel of a pumping step via use of circular frequency currents. Since the result on adjacent borders of computational spaces is "stitched" by making use of special interfaces such as "in place" [8], the last option is a strong fit only when used for the same number of rotor wheels and pump diffusers.

It should be noted that in all above cases, it is necessary to simulate three-dimensional turbulent flow in at least three stages of the pump in order to reduce charge and discharge devices' impact on characteristics.

The method of setting the boundary conditions, allowing calculating the characteristics of a single-stage pump with a lower cost of computing resources (Fig.4) is presented in this paper. The impeller intake and diffuser exit are connected by the periodic interface, which provides the flow stabilization in the step with the specified constant pressure differential corresponding to the pressure in the selected point of characteristics. The “impermeability” and "nonslip" conditions are assigned on fixed boundaries. The result of simulation is the current magnitude of the pump flow.

The comparison of the calculated characteristics of the stage (Fig.4, 5) with the experimental data [11] allows making the following conclusions:

1) good quality and satisfactory quantitative match of the results with the field stage testing data is obtained;

2) uprating of pump efficiency magnitudes (Fig.5) can be explained by the fact that in the calculations the textolite leathers friction of impellers against the pump diffusers boundaries and the friction in the bearings were not taken into account.

Modern technologies for polymeric products producing and processing include heat mass exchange procedures. [1,2]. Due to the complexity of modeling and analysis of such procedures using the mathematical model approach is necessary. Taking into account technological challenges, a new generation of computer technology and computer technology, polymers producing processes mathematical characterizations allow you to simulate in full. The process of modernization and improvement of production management polymeric products associated with the necessity of introducing an integrated automation.

2. The polymer product maceration

One of the principal features of the polymer production technology is the plasticizer’s application in the stages of preparation and formation of semi-finished items. Plasticizers provide the required plasticity and during subsequent process step are removed. The necessity to remove them from the composition of the polymer affects the entire manufacturing process of polymers in general [3], since the realization implies a complex set of successive heat mass exchange procedures involving, in particular, the removal of the ether, alcohol ousting with water and at list removing water or other types of drying [4].

The removing process of the solvent from the polymer product is responsible and prolonged [3]. In phase of dry- curing ester is removed which makes slowing the evaporation of the alcohol by water vapor saturation of the air approximately up to humidity of 70-85%. At the stage of maceration the group alcohol is removed. The maceration is based on mutual diffusion of water and alcohol [5]. The time of dry- curing and maceration is 36-40 hours.

The article considers the second phase of solvent removal process from the cylindrical shaped polymers. When the polymers maceration water is used for solvent extraction - alcohol and partly ether. At the process of polymers' maceration the water is used to remove solvent - alcohol and partly ether. Water is a medium for dissolving the polymer extracted from the element alcohol. Extraction is possible only in the case when the extractable substance’s volume fraction in the dissolution medium is lower than the volume fraction of it in substance from which it is extracted. [6].
Extraction is possible only in the case when the extractable substance's volume fraction in the dissolution medium is lower than the volume fraction of it in substance from which it is extracted. The process stops when the extraction equilibrium between the solution of alcohol in the polymeric product and solution in water.

The process stops when the extraction between the solution of alcohol in the polymeric product and solution in water is equaled. [7]

While the process of running these simulations were considered the following characteristics of the process: increasing the volume fraction of water in the alcohol helps to remove the ether in the process of maceration, however, an excessive increase in the volume fraction of the alcohol extraction is a reason other substances and disturbance of the polymeric structure.

Kinetically extraction obeys the laws mass exchange, convection and molecular diffusion and the laws of transfer extractable substances from the solid phase into the liquid phase [8; 9; 10].

Driving force of transferring the target component is the difference in chemical potentials of its phases.

At simulation following assumptions were made: the convective transfer is disparagingly small; polymeric elements' shrinkage is ignored, because the extracted alcohol is substituted with water (main shrinkage of polymers occurs in the phase of dry-curing).

Constructed simulator consist of nonlinear differential equation in partial differential coefficient second-order in cylindrical coordinates, the first of which describes the process of transferring alcohol and the second transfer process water inside the polymeric element:

\[
\frac{\partial U_c(r, z, \tau)}{\partial \tau} = \frac{1}{r} \frac{\partial}{\partial r} \left( r a_{mc} \frac{\partial U_c}{\partial r} \right) + \frac{\partial}{\partial z} \left( a_{mc} \frac{\partial U_c}{\partial z} \right) \tag{1}
\]

\[
\frac{\partial U_v(r, z, \tau)}{\partial \tau} = \frac{1}{r} \frac{\partial}{\partial r} \left( r a_{mv} \frac{\partial U_v}{\partial r} \right) + \frac{\partial}{\partial z} \left( a_{mv} \frac{\partial U_v}{\partial z} \right) \tag{2}
\]

where \( r, z \) - spatial coordinates of the selected cylindrical coordinate system;
\( U_c(r, z), (U_v(r, z)) \) - alcohol (water) concentration in the polymeric products;
\( a_{mc}, a_{mv} \) - the diffusion coefficient of the alcohol (water).

The diffusion coefficients depend on the temperature and mass content of the current value:

\[
a_{mc} = a_{mc0} U_c^{n_1} T^{m_1}; \quad a_{mv} = a_{mv0} U_v^{n_2} T^{m_2}; \tag{3}
\]

where \( T \) - temperature; \( a_{mc0}, a_{mv0} \) - the self-diffusion coefficients of water and alcohol;
\( n_1, n_2, m_1, m_2 \) - some constants, which are calculated experimentally.

Differential equations with partial derivatives are generally countless solutions, therefore the formulation of a diffusion model of a porous material extraction grain polymer will be terminated if, in addition to the diffusion equation (1) and (2) will be [11] the condition of uniqueness - the initial and boundary conditions.

At the initial time \( \tau = 0 \) the concentration distribution of alcohol and water in the polymer have some specified value (final conditions of dry-curing):

\[
U_c(r, z, 0) = \text{const} = Q_c; \quad U_v(r, z, 0) = \text{const} = Y_v. \tag{4}
\]

For the description of maceration the most used are boundary conditions of the first kind.

On the external boundary the conditions must be fulfilled:

\[
U_c(R, z, \tau) = U_c(R_k, z, \tau) = c(\tau) a U_c(r, \frac{1}{2}, \tau) = c(\tau) \left. \frac{\partial U_c}{\partial z} \right|_{z=0} = 0; \tag{5}
\]

\[
U_v(R, z, \tau) = U_v(R_k, z, \tau) = 1 - c(\tau) a U_v(r, \frac{1}{2}, \tau) = 1 - c(\tau) \left. \frac{\partial U_v}{\partial z} \right|_{z=0} = 0.
\]
The boundary conditions (5) show the border has an alcohol solution in water with a concentration \( c(\tau) \), but the concentration of water in the solution is \( 1 - c(\tau) \).

\( c(\tau) \) – the current concentration of alcohol in the pool, which is calculated by the formula:

\[
c(\tau) = \frac{(Q_1 - \bar{U})m_nN_n}{m_v + (Q_1 - \bar{U})m_nN_n(1 - \frac{p_v}{p_c})},
\]

where \( m_n \) - mass of III, kg; \( m_v \) - mass of water, kg; \( \bar{U} \) - average integral concentration of alcohol; \( N_n \) - number of polymer cylinders in the pool; \( p_v \) - water density; \( p_c \) - alcohol density.

Alcohol mass in the pool, as well as \( \Delta m_{воды} \) – water mass, diffused into the polymer product, we find, on the basis of knowing the solution of the mikrokinetik problem - the change of alcohol and water average integral concentration.

\[
\bar{U}(\tau) = \frac{1}{V} \iiint r \cdot U(r, z, \tau) \, dr \, dz.
\]

Based on the model was developed numerical method of calculation [8; 11], and implemented a program complex calculation of the kinetics of the process of soaking. The resulting model of the dynamic properties adequate object. The simulation results show the effect on the number of fills, the processing time and the duration of the process from its initial temperature and solvent content. The bath module affects marginally. [13].

The construction of mathematical models is an effective tool to study process. Simulation is also necessary to optimize processes and to create automated process control systems.

3. References

[1]. GOST 6134-2007 (ISO 9906:1999). Dynamic pumps. Test methods.
[2]. Sherstyuk A N Pumps, fans and compressors: textbook for colleges. 1972 Moscow, 344 pp.
[3]. Zharkovsky A A Simulation of viscous flow in the centrifugal pump impeller 2011 Compressors and pneumatics. №4. – P.18.
[4]. Slobodkina FA Fluid flow in centrifugal pump step 2008 Mathematical modeling №10. – P. 51-63.
[5]. Shih T.-H., Liou, W W, Shabbir A, Yang Z. and Zhu J. 1994. A New k-\( \varepsilon \) Eddy Viscosity Model for High Reynolds Number Turbulent Flows – Model Development and Validation, NASA TM 106721.
[6]. Lomakin V O Verification of calculation results in the computational fluid dynamics package STAR-CCM+ flowing part of a centrifugal pump AKh 50-32-200 / V O Lomakin, A I Petrov // Journal of higher schools. Engineering., 2012. – №5. – Pp. 6-9.
[7]. Sheypak A A Experimental and computational study of the centrifugal pump characteristics / A. A. Sheypak, Ya. K. Lokhansky, A. S. Pozdynakov // Mechanical industry and engineering education. – 2009. – № 1. – Pp. 53-61.
[8]. User Guide STAR-CCM+ Version 7.04.006. - CD-adapco, 2012.
[9]. Loitsyanskii L G Mechanics of fluid and gas.2003 – 7-th ed., corr. – Moscow, 846 pp.
[10]. Abdullin I Sh, Galyautdinov R T and Kashapov N F Inzhenerno-Fizicheskii Zhurnal 200474 (5) 104-107
[11]. Installation of submersible centrifugal pumps (UETsNA) in full set: serial production catalogue.2008 JSC "ALNAS".