Research of centrifugal gas-liquid separator

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Abstract. The article is devoted to research of centrifugal gas-liquid separator. The fields of application of gas separators are described. Parameters on which depends the separation process are revealed. The mathematical model used in computer simulation of the two-phase flow is presented. The figures of the scalar physical quantities distribution in the flow part of the separator are shown. Graphs of the gas separator's characteristics are given.

1. Introduction

A separator is a device that separates a product into fractions with different characteristics. These devices are widely used in various spheres of human activity, such as agriculture, mining, medicine, food industry, etc. Figure 1.

In this article the gas separator intended for reduction of volume content of gas to admissible values in a mix arriving in the centrifugal pump as at the raised gas content its work becomes unstable and is characterised by fluctuations of working parameters: feed, created pressure and consumed power is considered [1,2]. Fluctuations in pump parameters lead to increased vibration of the unit and, consequently, to low operating hours.

Fig. 1. Example of a gas separation plant
A further increase in gas content leads to a feed failure. There are three types of gas separators: gravity, eddy and centrifugal. The last one is the most effective and was discussed further. Figure 2.

The principle of operation of such separator is based on the action of centrifugal force separating gas from water. The arriving mixture enters the intake ports and moves to the screw type inducer, from where it moves to the centrifuge with increased pressure, where it is divided into phases (under the influence of inertia forces the heavier fraction is pressed against the walls, and the lighter one remains near the shaft). After that the liquid is fed to the pump and the gas goes into the annulus.

Numerous studies have shown that the efficiency of the separator depends on parameters such as flow rate and gas content of the mixture [3,4,5,6]. With the help of modern methods of hydromodelling, the influence of these factors on the pressure, power and separation coefficient of the unit has been considered in this article.[7,8,9,10]. The mathematical model of running processes was also described. In addition, the negative influence of backflow was revealed. [11,12,13].

![Fig. 2. Centrifugal gas separator design scheme](image)

The main purpose of this work is to study the influence of input parameters on the efficiency of the gas separator.

2. Mathematical model and methods.
This paper uses the model of multiphase flow of incompressible liquid (\(\rho=\text{const}\)). Numerical modeling is based on solving discrete analogues of basic equations of hydrodynamics.
Calculation is carried out on the basis of mathematical model of divided multiphase flow.[14,15,16] That is, the equations of mass transfer and the amount of motion are solved separately for each phase, but the pressure field is the same for all phases.

The mathematical model consists of a set of differential and algebraic equations:

1. The phase volume in each calculation cell is calculated as follows:

\[ V_i = \int \alpha_i dV \]

where \( \alpha_i \) – the concentration of the \( i \)-phase in the cell.

The sum of concentrations of all phases in the cell is equal to one

\[ \sum_{i=1}^{n} \alpha_i = 1 \]

2. Mass conservation equation (continuity equation):

\[ \frac{\partial}{\partial t} \int \alpha_i \rho_i dV + \int A \alpha_i \rho_i V_i d\hat{\alpha} = 0 \]

where \( \rho_i \) – \( i \)-phase density

\( V_i \) – \( i \)-phase velocity (in case of modeling of turbulent flow by RANS-type model - time averaged)

3. Equation of the change in the amount of motion:

\[ \frac{\partial}{\partial t} \int \alpha_i \rho_i V_i dV + \int A \frac{\partial}{\partial \hat{\alpha}} (\alpha_i V_i) d\hat{\alpha} = -\int \alpha_i \nabla p dV + \int A \alpha_i \nabla \cdot V d\hat{\alpha} + \int M_i dV \]

where \( (V_i V_i) \) – tensor product of velocity vectors of the \( i \)-nd phase.

\( p \) – pressure

\( \vec{g} \) – mass force intensity vector (in this case, gravity force 9.81 m/s² and inertia force from the rotation of the calculation area)

\( T_{ii} \) - molecular viscosity stress tensor

\( T_{ii}^t \) – turbulent stress tensor

\( \vec{M} \) – vector of total intensity of interphase interaction forces per unit volume, for the vector \( \vec{M}_i \):

\[ \sum_i M_i = 0 \]

Vector \( \vec{M}_i \) characterizes all the forces by which the individual phases interact with each other.

\[ M_i = \sum_{j=1}^{n} \left( F_{ij}^{D} + F_{ij}^{TM} + F_{ij}^{L} + F_{ij}^{TD} + F_{ij}^{WL} \right) \]

\[ \vec{M}_i = \sum_{j \neq i} \left( F_{ij}^{D} + F_{ij}^{TM} + F_{ij}^{L} + F_{ij}^{TD} + F_{ij}^{WL} \right) \]
Where
\[ F_{ij}^D \] – resistance force
\[ F_{ij}^{VM} \] – virtual mass strength
\[ F_{ij}^L \] – lifting force
\[ F_{ij}^{TD} \] – force caused by turbulent dispersion
\[ F_{ij}^{WL} \] – the force caused by the wall effects

The semi-empirical model k-\(\omega\) SST turbulence model well-proved in the calculation of dynamic machines was used for this task[17,18,19,20]. The flow part of the gas separator was simulated on a grid consisting of 580 thousand cells. The cells in the flow core have a multi-faceted shape, while the solid walls of the pipe have a prismatic shape. The design grid for fluid body is shown in Figure 3.

3. Results and analysis

The calculated speed as an initial condition was set at the outlet boundary of the separated water in order to comply with the condition of equal pressure at the inlet and outlet of the gas separator into the pipe with unseparated fluid. Therefore, in order to compare the data at different phase ratios, graphs of the gas separation factor (Fig. 4), power (Fig. 5), head (Fig. 6) on the flow rate at the boundary where the speed was specified were made.

Fig.3. Mesh

Fig.4. Gas separation factor
Fig. 5. Power

Fig. 6. Head
Figure 7 shows the scene of volume fraction distribution. One can observe that the heavier fraction is pressed against the walls under the influence of inertial forces, while the lighter fraction remains near the shaft. Significant phase separation occurs in the centrifuge.

For the most visual representation of a picture of a flow in a gas separator flowing part in figure 8,9 scalar scenes of pressure and speed distribution at Q=136,7 m³/day and a phase ratio on an input 75 % water, 25 % gas are shown.
4. Conclusions.
According to the results of the performed calculations, ambiguous dependences of the gas separation coefficient on the flow rate at different gas contents were obtained. Similar behavior of the coefficient value is apparently related to the mechanism of interaction between the screw inducer and the centrifuge when working on a mixture of air and water. In this paper, the study of the entire gas separator without studying the nature of the flow in its individual elements was carried out. Also it can be noticed that separation coefficient is high at low gas content. In addition, there is a flow rate range in which the optimum operating mode is observed (the lowest power with a high separation factor, in this case at a flow rate of $130\ldots150m^3/day$). To obtain a more detailed picture and explanation of the dependencies type further research is required including the flow simulation of individual components of the unit.

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