The calculation of multiphase flows in flowing parts of centrifugal pump

M Saprykina[1,2] and V Lomakin[1]

[1]Bauman Moscow State Technical University

[2]E-mail: marias108@mail.ru

Abstract. The effect of gas content on the changing of head of a centrifugal pump is researched. The method of numerical hydrodynamic modeling is used for solving this problem. The using mathematical models are described and compared. The results of the simulation of fluid flow, which are depended on the air content, are presented. The data on the changing of head and the termination of its work are obtained.

Introduction

The variety of pumped fluids by phase composition can be classified into single-phase (contain only the liquid phase), two-phase (contain liquid and solid or liquid and gaseous phases) and three-phase (contain liquid, solid and gaseous phases). Therefore, the problem of pumping hydraulic mixtures is important for many industries. [1]–[5]

The development of a number of industries which are related to the processing and movement of gas-saturated suspensions (oil producing, oil refining, food, microbiological, etc.) requires the creation of special pumping equipment capable of efficiently pumping products with a high level of gas content in the pumped mixture. At the same time, the main operational requirements for the specified pumping equipment are: a) the maximum gas content of the pumped medium, b) profitability, c) overall dimensions. [6]–[7] Based on this, it follows that the main criterion that determines the level of production costs for the consumer is the maximum gas content of the pumped medium, pushing the indicator of pump efficiency to the background.

The operation of pumping equipment is complicated by the presence of free gas. It is received with the submersible pump as a part of the gas-liquid mixture as a result of the process of oil degassing. Free gas can have a negative effect on the operation of the pump, which will lead to increasing in the consumed electric power in comparison with the data of the rating characteristics, to decreasing in the mean time between failures of both individual elements and the entire pumping unit as a whole. It will also lead to decreasing in the technological efficiency of oil production from wells. [8]–[10]

In the case of pumping mixtures of liquid and gas, these pumps have several disadvantages, which include a low efficiency and disruption of the parameters with excessive gas content in the pumped medium. In this regard, special attention is required to analyze the concept of the quality of work of dynamic pumps in hydraulic mixtures in general and in GHS separately. Whenliquids with a high gas factor are pumped, the total technical and economic indicators of the quality of the pumping equipment are most acceptable not only in relation to the usual efficiency when the pump is running on clean liquid. Today, other indicators require greater attention, including the "stable operation" of a dynamic pump. The concept of "stable operation" refers to the ability of a pump to operate on a GHS

without losing its performance at high levels of gas content in the pumped mixture. Loss of performance occurs due to disruption of the pump parameters (there is a complete cessation of its supply). [11]–[12]

The problem of stalling parameters is relevant for all vane pumps. An analysis of the technological regimes of the well operating stock shows upthat now there are a number of unresolved tasks for the effective control of the pump in high gas conditions. Thus, when analyzing the existing literature on this topic, it was revealed that the process of oil production from wells under free gas conditions is relevant and requires additional research. [13]

Mathematical model of multiphase fluid flow
In this paper, we use the model of a multiphase incompressible fluid flow (ρ = const). Numerical simulation is based on solving discrete analogs of the basic hydrodynamic equations.The two approaches of calculation multiphase fluid flow were used in this research.

The first calculation is carried out on the basis of a mathematical model of a divided multiphase flow. That is, the equations of mass and momentum are solved separately for each phase. Yet, the pressure field is the same for all phases. The developed pump is used in the system of formation water purification. It supplies the working fluid to the flotation machine. It pumps a two-phase medium: water-air. Numerical hydrodynamic modeling was performed in the StarCCM + software package. [14]–[15]

The mathematical model consists of differential and algebraic equations:
1. The volume of the i-th phase in computional cell is calculated as:

$$V_i = \int_V \alpha_i dV,$$

where α_i — the concentration of the i-th phase in the cell.

The sum of the concentrations of all phases in the cell is one.

$$\sum_{i6}^{n} \alpha_i = 1.$$

2. The equation for conservation of mass (continuity equation):

$$\frac{\partial}{\partial t} \int_V \alpha_i \rho_i dV + \int_A \alpha_i \rho_i \vec{V_i} d\vec{a} = 0,$$

where ρ_i — the i-th phase density; $\vec{V_i}$ — the i-th phase velocity (in the case of turbulent flow modeling by a RANS-type).[16]–[18]

3. The equation of the changing in the amount of motion:

$$\frac{\partial}{\partial t} \int_V \alpha_i \rho_i \vec{V_i} dV + \int_A \alpha_i \rho_i \left(\vec{V_i}\vec{V_i} \right) d\vec{a} = -\int_V \alpha_i \nabla p dV +$$

$$+ \int_V \alpha_i \rho_i \vec{g} dV + \int_A \left[\alpha_i \left(T_i + T_i^t \right) \right] d\vec{a} + \int_V \overrightarrow{M_i} dV,$$

where $\left(\vec{V_i}\vec{V_i} \right)$ — the tensor product of the velocity vectors of the i-th phase; p — the pressure; $\vec{g}$ —the mass intensity vector (in this case, the gravity force is 9.81 m / s2 and the inertial force due to the rotation of the computational area); T_i — the molecular viscosity stress tensor; T_i^t — the turbulent

stress tensor; $\vec{M}$ —the vector of the total intensity of interfacial interaction forces per unit volume, for the vector $\overrightarrow{M_i}$ the equality is:

$$\sum_i \overrightarrow{M_i} = 0.$$

The vector $\overrightarrow{M_i}$ characterizes all the forces that separated phases interact with each other.[19]–[22]

$$\overrightarrow{M_i} = \sum_{i \neq j}\left(\overrightarrow{F_{ij}^D} + \overrightarrow{F_{ij}^{VM}} + \overrightarrow{F_{ij}^L} + \overrightarrow{F_{ij}^{TD}} + \overrightarrow{F_{ij}^{WL}}\right),$$

where $\overrightarrow{F_{ij}^D}$ — the resisting force; $\overrightarrow{F_{ij}^{VM}}$ — the power of the virtual mass; $\overrightarrow{F_{ij}^L}$ — the ascensional power; $\overrightarrow{F_{ij}^{TD}}$ — the turbulent dispersive force; $\overrightarrow{F_{ij}^{WL}}$ — the force, which is caused by wall effects.

In fig. 1 the computational grid for hydrodynamic modeling is shown.
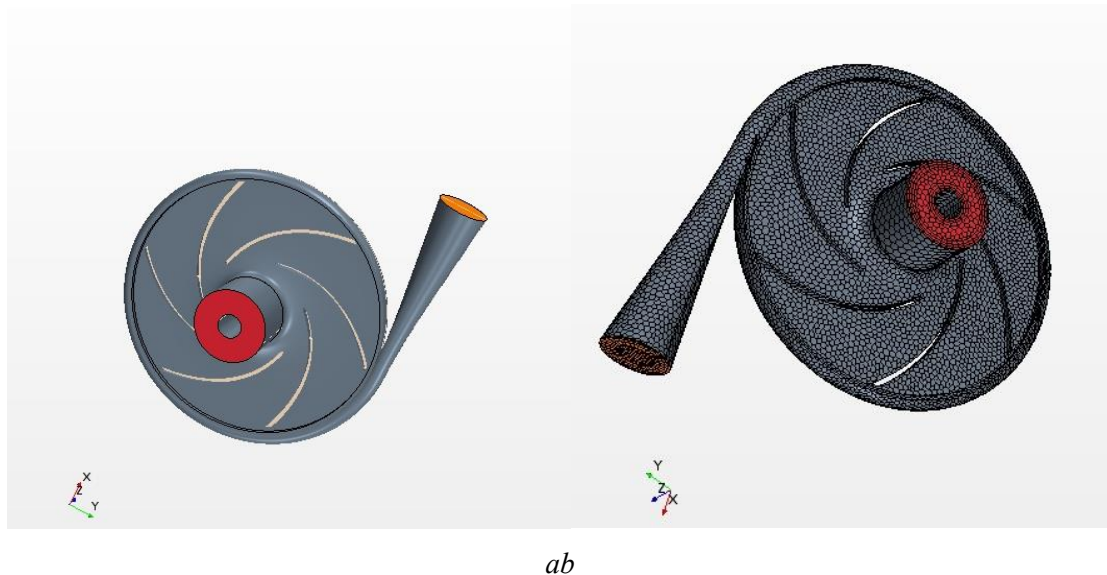

ab

Fig. 1. The computational grid
a — 3d model; b — section.

The VOF Multiphase model is used to solve problems involving immiscible fluid mixtures, free surfaces, and phase contact time. In such cases, there is no need for extra modeling of inter-phase interaction, and the model assumption that all phases share velocity, pressure, and temperature fields becomes a discretization error.

The Volume of Fluid (VOF) multiphase model implementation in Simcenter STAR-CCM+ belongs to the family of interface-capturing methods that predict the distribution and the movement of the interface of immiscible phases. This modeling approach assumes that the mesh resolution is sufficient to resolve the position and the shape of the interface between the phases.

Thus, this model combines air and liquid in one phase with the same speed. After the creating an air bubble and the beginning of the simulation process, it was revealed that this model has a more stable result and the solution converges. It was decided to calculate with this method.

Calculation results

In fig. 2 the visualized data on the volume of air in the calculated pump are shown. The approach of calculation was **Multiphase Segregated Flow**.
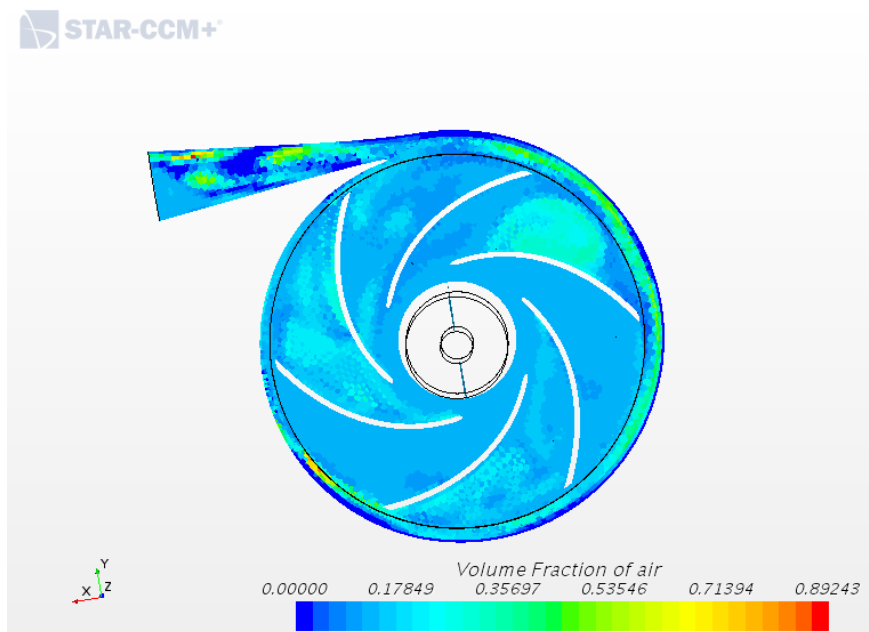

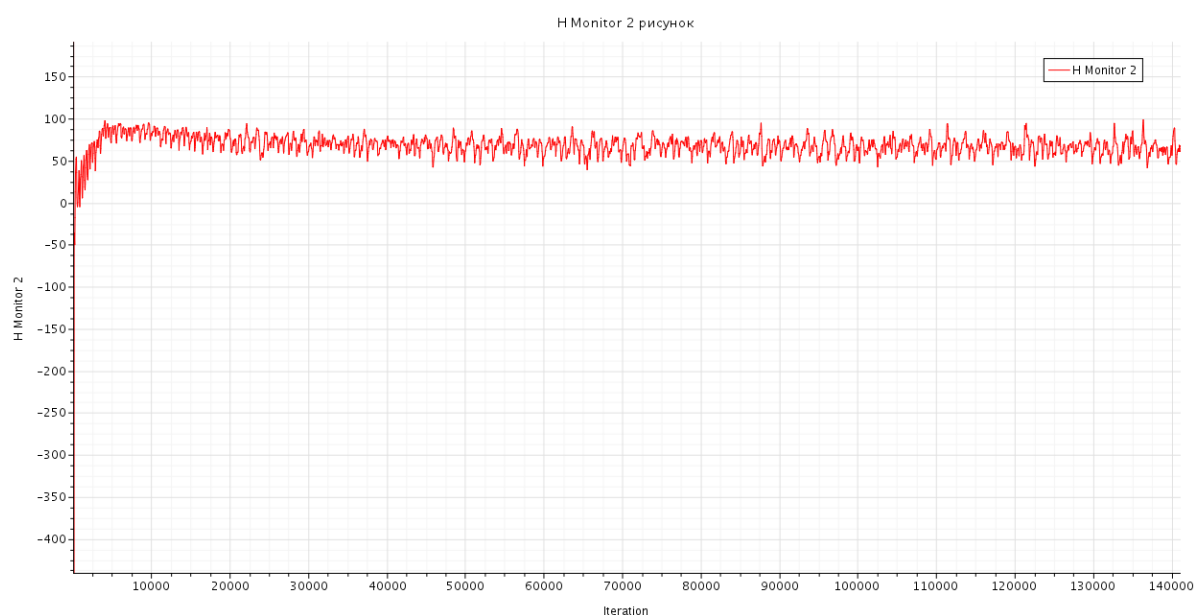**Fig. 2.** The results of simulation

Fig. 3. Theheadgraph

The graph shows that the head practically does not decrease at a percentage of air around 13%. The solution is unstable. Air bubbles do not accumulate but they dissolve throughout the fluid. In this case the pump does not notice the air and works correctly. According to this fact the present method of calculation does not bring rights results.

It was decided to calculate with Volume of Fluid. The figure 4 shows the simulation results at a percentage of air 13%.
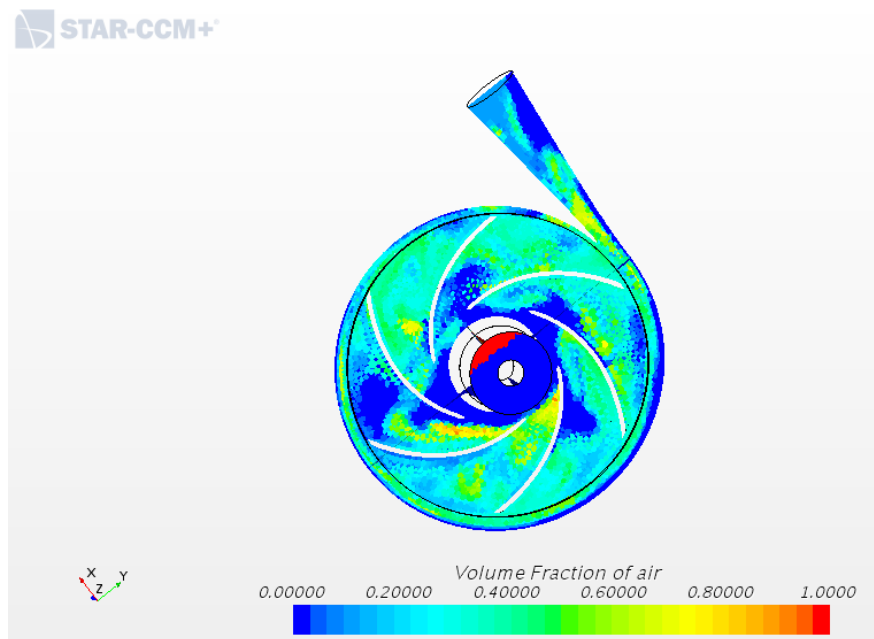
Fig. 4. VOF'ssimulation.
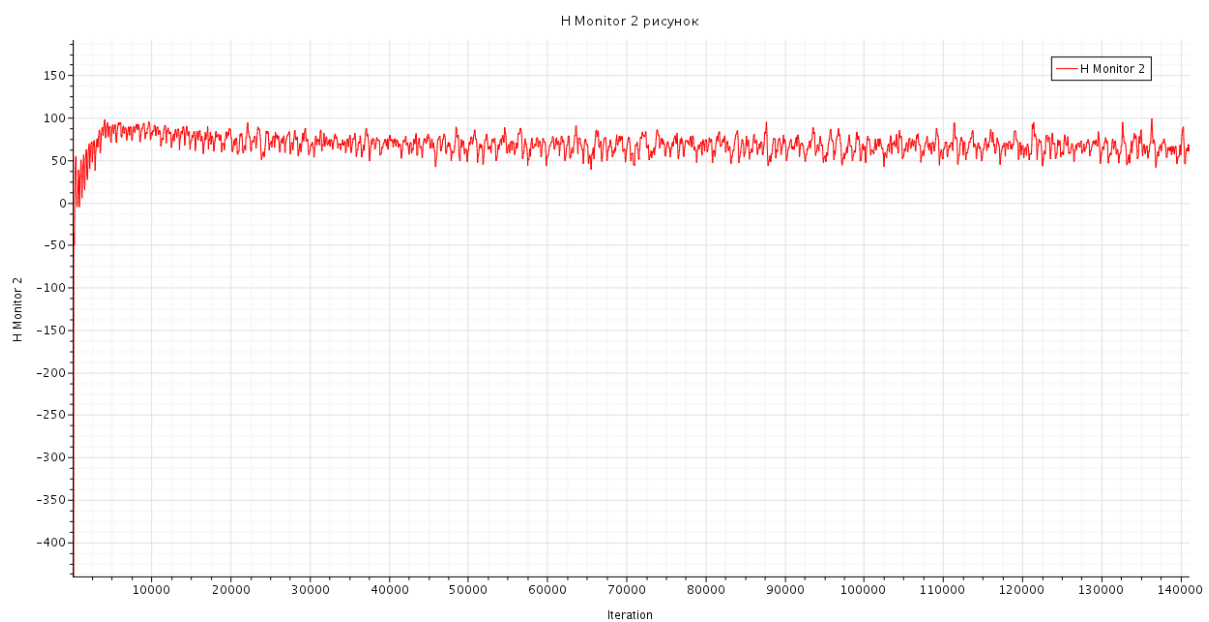
Infig. 5 the head's dropping can be seen.

Fig. 5. Theheadgraph

In fig. 6-8 many different simulations-visualizations of percentage of air are shown. Besides, the data of head is shown too.
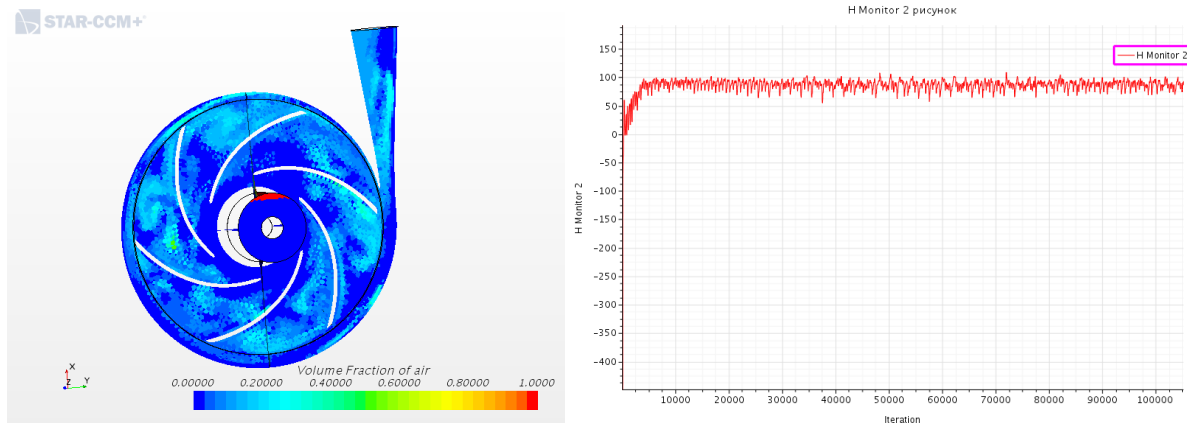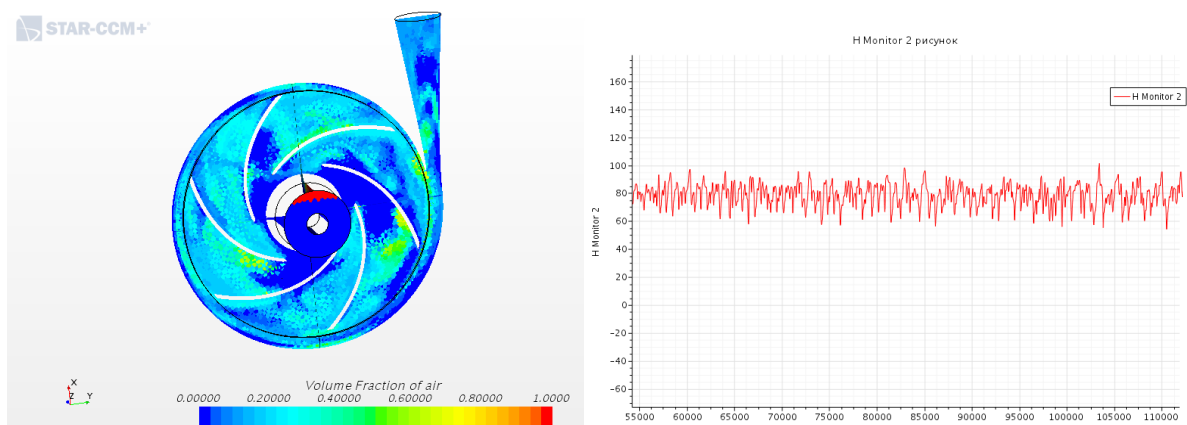
Fig. 6. The volume of air 5%.
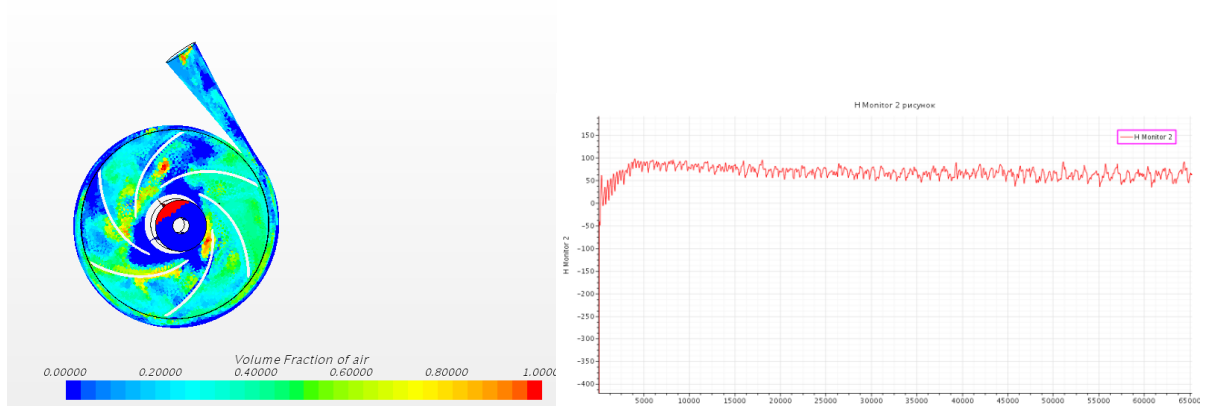

Fig. 7. The volume of air10%.

Fig. 8. The volume of air15%.

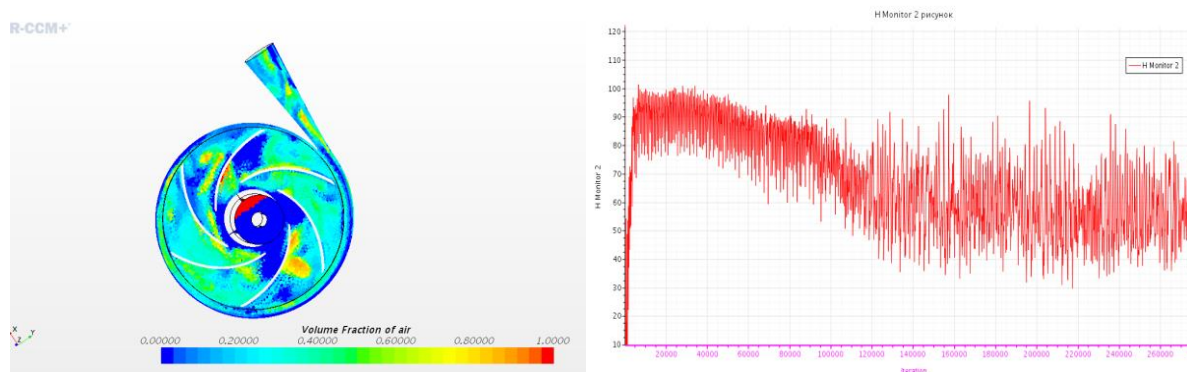Fig. 9 shows a sharp head's drop- the breakdown.

Fig. 9. The volume of air 17%.

When study was finished, the graph was obtained reflecting the dependence of the head on the air content in the pumped liquid and also an estimated breakdown point.
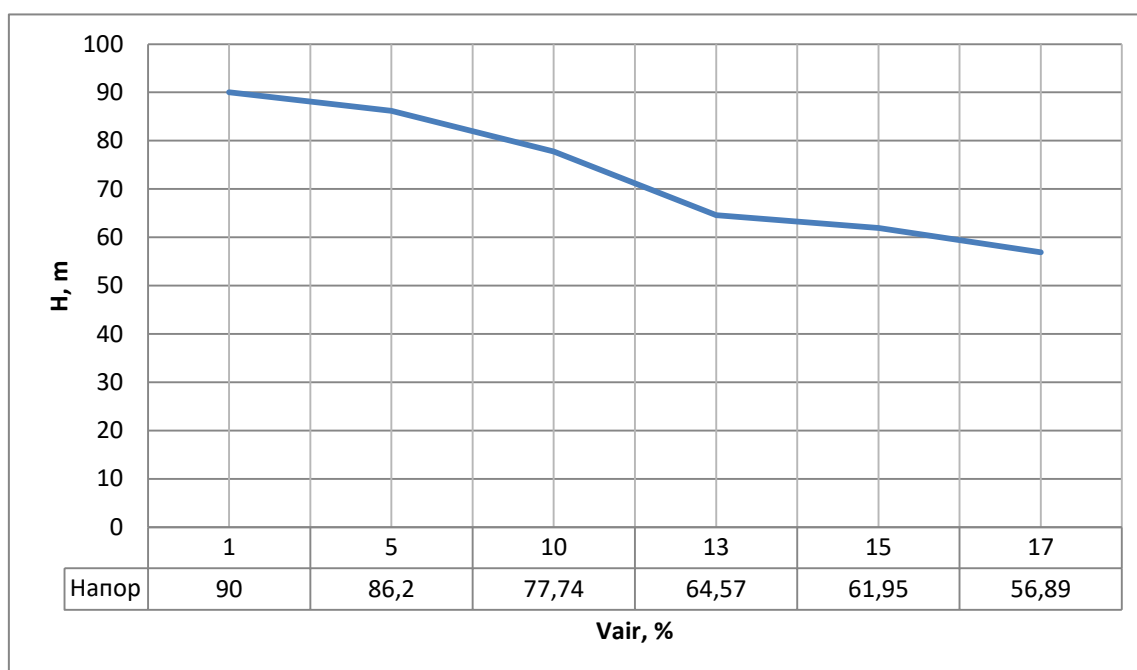

	1	5	10	13	15	17
Напор	90	86,2	77,74	64,57	61,95	56,89

Vair, %

Fig. 10. The graph shows dependence between the volume of air and the head.

Conclusion

The analysis showed the effectiveness of the mathematical model VOF.The calculation showed that this method correctly reflects the behavior of the pump when the gas content is changing. Besides, it can also be widely used to find the breakdown point.

The proposed method of calculation and setting the boundary conditions allows to achieve a significant dropping of the head with low gas content at the inlet. The head dropped by a third with a gas content of 15 %.

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