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The evaluation of the effect of gas content on the characteristics of a Centrifugal Pump

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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 model is described. 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

In these latter days, many people have to deal with a rather large number of complicated factors with oil production. These include the greater curvature of the wellbore, small diameters of the casing, high gas content, removal of mechanical impurities, salt deposition, high temperature of the liquid and others [1].

The effect of the gas factor complicating the operation of a centrifugal pump is regarded in this article. The gas factor is one of the most important one while you are choosing the method of operation and designing the optimal operation mode of the reservoir-well system. The presence of gas in the oil / water mixture also changes the behavior of the pump. The value of the optimal gas content will additionally depend on the properties of the oil and the water content in the mixture. The submersible centrifugal pump is quite sensitive to the presence of free gas in the pumped liquid. The characteristics of the pump are deformed because of its dependence on quantity of gas content.

The presence of free gas limits the work of the ECP, because:

- free gas reduces the volume of fluid in the ECP stage;
- separation of liquid and gas in the centrifugal force field reduces the pressure of the stage;
- “gas impurity” is forming in the first steps of the pump and accumulating at the center. It blocks the flow of liquid, which leads to disruption of the pump supply. [2] - [4]

Numerous and long-term studies of the work of the ESP system made it possible to identify three qualitatively different areas of the work of centrifugal pump. It is pumping out the gas-liquid mixture. In the first area, which is characterized by a small content of free gas in the pumped liquid, the actual characteristics of the pump do not differ from the bench characteristics for a pure liquid (there is no free gas), and the efficiency of the pump is maximum. The pressure at the pump intake, corresponding to small gas content in the pumped liquid, is the optimum pressure at the inlet. The second area of work of the ECP is characterized by increasing of free gas quantity in the pumped liquid. As a result the actual characteristics of the pump differ from the bench ones when the pump works without free gas.



Yet, the pump maintains stable operation with an acceptable efficiency. The inlet pressure in this area of the work of free gas pump is called the admissible inlet pressure. The third area of work of the ECP is characterized by a significant amount of free gas in the pumped liquid, as a result the stable operation of the pump is disturbed until the supply is interrupted. In this case, the efficiency of the pump is significantly reduced (down to zero when the supply is disrupted), and long-term operation of the ECP in this area becomes impossible. [5]

When the existing literature analysis on this topic was conducted, it was revealed that there is no complete research on this topic. Thus, in [6], the effect of the gas factor was studied in conjunction with others one during the overhaul period of operation of the reservoir-well-pump system. In [7] - [8] the main attention is paid to the review and development of dispersing devices for pumping gas liquid mixture from wells. To conclude, the scientific literature has no studies and articles covering all aspects of the effect of gas content on the pump operation.

Mathematical model of multiphase fluid flow

In this paper, we use the model of a multiphase incompressible fluid flow ($\rho = \text{const}$). Numerical simulation is based on solving discrete analogs of the basic hydrodynamic equations.

The 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. [9] - [11]

The mathematical model consists of differential and algebraic equations:

1. The volume of the i -th phase in computational 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.

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

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

$$\frac{\partial}{\partial t} \int_V \alpha_i \rho_i dV + \int_A \alpha_i \rho_i \bar{V}_i d\bar{a} = 0,$$

where ρ_i – the i -th phase density; \bar{V}_i – the i -th phase velocity (in the case of turbulent flow modeling by a RANS-type). [12]-[15]

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

$$\begin{aligned} \frac{\partial}{\partial t} \int_V \alpha_i \rho_i \bar{V}_i dV + \int_A \alpha_i \rho_i (\bar{V}_i \bar{V}_i) d\bar{a} = & - \int_V \alpha_i \nabla p dV + \\ & + \int_V \alpha_i \rho_i \bar{g} dV + \int_A \left[\alpha_i (T_i + T_i^t) \right] d\bar{a} + \int_V \bar{M}_i dV, \end{aligned}$$

where $(\bar{V}_i \bar{V}_i)$ – the tensor product of the velocity vectors of the i -th phase; p – the pressure; \bar{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 \vec{M}_i the equality is:

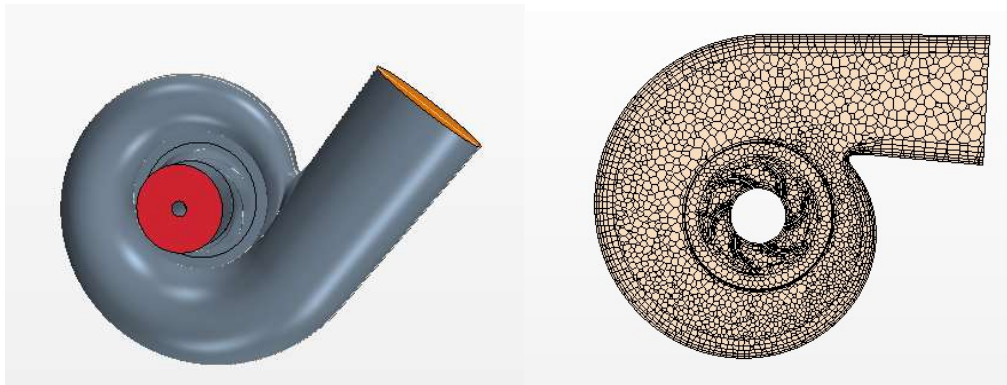
$$\sum_i \vec{M}_i = 0.$$

The vector \vec{M}_i characterizes all the forces that separated phases interact with each other.[16]-[20]

$$\vec{M}_i = \sum_{i \neq j} \left(\vec{F}_{ij}^D + \vec{F}_{ij}^{VM} + \vec{F}_{ij}^L + \vec{F}_{ij}^{TD} + \vec{F}_{ij}^{WL} \right),$$

where \vec{F}_{ij}^D – the resisting force; \vec{F}_{ij}^{VM} – the power of the virtual mass; \vec{F}_{ij}^L – the ascensional power; \vec{F}_{ij}^{TD} – the turbulent dispersive force; \vec{F}_{ij}^{WL} – the force, which is caused by wall effects.

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



aб

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

The pump was calculated with a changing of the volume fractions of water and air in order to determine the time when the head will drop and its operation will stop. The head was calculated by the following formulas:

$$H = \frac{p_2 - p_1}{\rho_w \cdot g},$$

где p_1 — the pressure in 1 dimensional section, Pa; p_2 — the pressure in 2 dimensional section, Pa; ρ_w — the water density, 1000 kg/m³; g — the acceleration of gravity, m/s².

When a two-phase medium are being pumped, the head should be considered to take into account changes in the density of the pumped medium, which is calculated by the formula:

$$\rho = \frac{m}{V} = \frac{\alpha_1 \cdot V \cdot \rho_1 + \alpha_2 \cdot V \cdot \rho_2}{V} = \alpha_1 \cdot \rho_1 + \alpha_2 \cdot \rho_2,$$

where α_1 — the water volume fraction; ρ_1 — the water density, kg/m³; α_2 — the air volume fraction; ρ_2 — the air density, kg/m³.

Therefore, the head, which was received by the StarCCM + software, was adjusted for the calculated density:

$$H_1 = H \cdot \frac{\rho_w}{\rho},$$

where H — the head, which was received by the StarCCM+, m; ρ_w — the water density, kg/m³; ρ — calculated density of the two-phase medium, kg/m³.

For the convenience of evaluation the effect of gas content on the pump head, the relative head was also calculated:

$$\bar{H} = \frac{H_1}{H_u},$$

where \bar{H} — the relative head, m; H_u — the ideal head, 10,5 m; H_1 — the correct head, m.

Calculation results

In fig. 2 the visualized data on the volume of air in the calculated pump are shown.

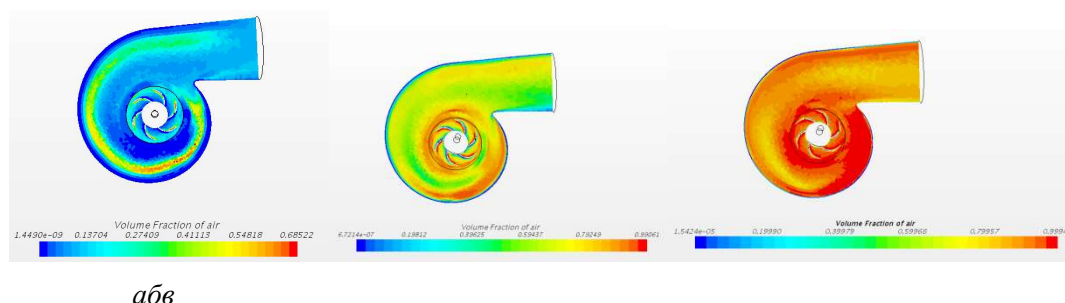
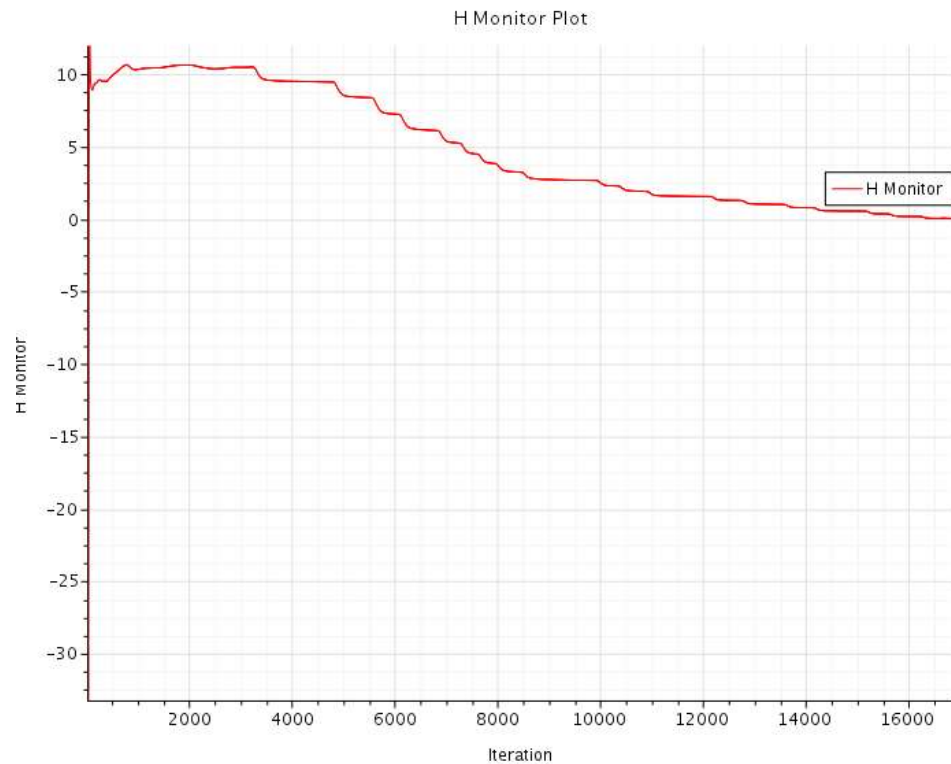
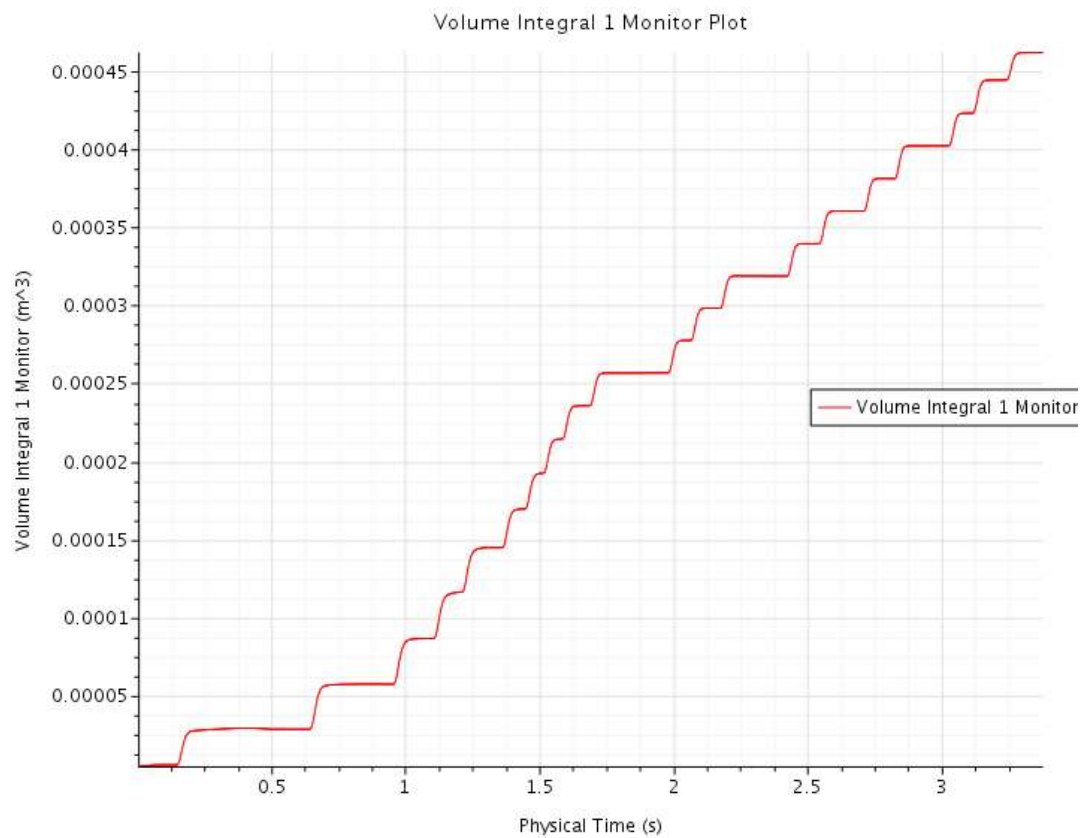


Fig. 2. The air volume visualization

a — $\varphi_{air} = 10\%$; б — $\varphi_{air} = 60\%$; в — $\varphi_{air} = 90\%$.

From the STAR CCM + software package the necessary graphs were obtained. They are shown in fig. 3 and 4.

**Fig. 3.**The head graph**Fig. 4.**The volume of air graph

The data on the head and volume of air in the developed pump was taken from the graphs. According to the formula the relative head was calculated. The results are presented in table 1.

Table 1.The results

Φ_{air}	Φ_{water}	H	H_1
0,01	0,99	10,551	10,656
0,05	0,95	10,368	10,598
0,1	0,9	9,473	10,523
0,15	0,85	8,391	9,871
0,2	0,8	7,251	9,062
0,25	0,75	6,124	8,162
0,3	0,7	5,271	7,525
0,35	0,65	4,548	6,992
0,4	0,6	3,879	6,461
0,45	0,55	3,187	5,789
0,5	0,5	2,676	5,346
0,55	0,45	2,345	5,104
0,6	0,4	1,924	4,801
0,65	0,35	1,565	4,461
0,7	0,3	1,292	4,295
0,75	0,25	1,018	4,057

Окончание табл. 1

Φ_{air}	Φ_{water}	H	H_1
0,8	0,2	0,785	3,906
0,85	0,15	0,553	3,662
0,9	0,1	0,366	3,621
0,95	0,05	0,183	3,578
0,99	0,01	0,046	3,501

According to the data of the table, the dependence of the head on the amount of air in the pump under study was plotted and performed on fig.5.

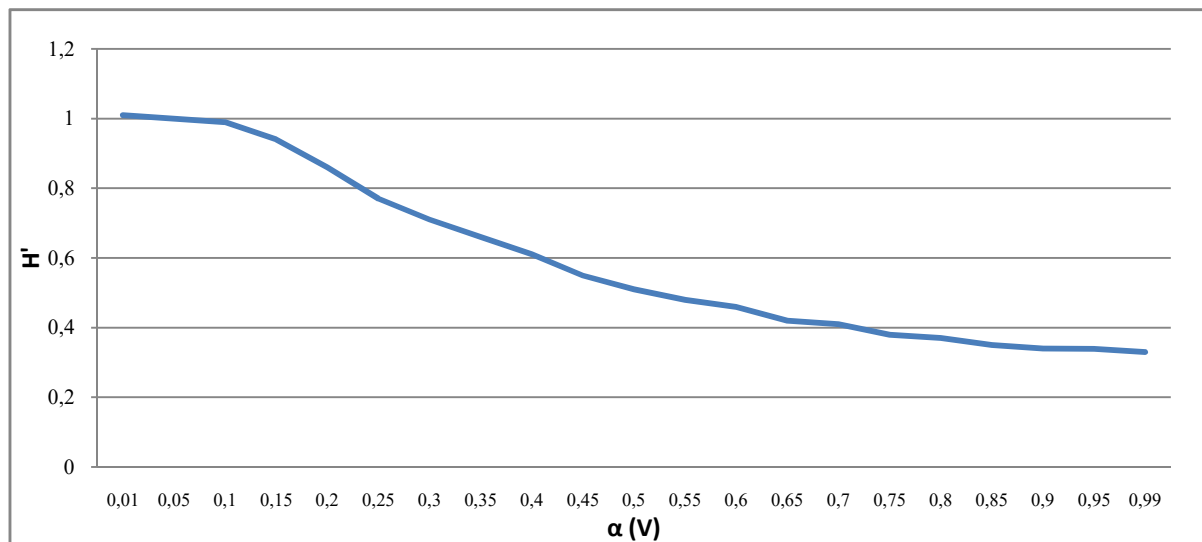


Fig. 5 The dependence of the head on the amount of air

Conclusion

The analysis showed the effectiveness of the application of this mathematical model. The calculation showed that the head of the pump is a function of the density of the pumped medium, in the case of pumping a two-phase medium. The head is dropping with increasing gas content. That is associated with an uneven distribution of phases in the blade channel.

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