Effect of gas content in the pumped liquid on the characteristics of a torque flow pump

S Sapozhnikov¹, S Antonenko¹, V Miltykh¹, V Moskalenko¹, A Mandryka¹

¹ Department of Applied Hydroaeromechanics, Sumy State University, 2, Rymskogo-Korsakova st., Sumy, Ukraine

E-mail: s.sapozhnikov@pgm.sumdu.edu.ua

Abstract. The article considers one of the ways to increase the ability of a dynamic pump to pump gas-liquid mixtures - the application of the vortex principle of energy transfer. This scheme is embodied in a torque flow pump, which is able to pump mixtures with a gas content of up to 0.40 - 0.45 without additional devices for preparing the mixture. Experimental researches the influence the value of the volumetric gas content on the performance characteristics of the torque flow pump of the “Turo” type are given. The analysis of influence of structure of a stream of gas-liquid mixture on the value of the critical gas content in the interblade channels of the impeller is represented and developed a physical model of decrease the parameters of the torque flow pump.

1. Introduction

The need for pumps which pumping gas-liquid mixtures exists in the energy complex, microbiological, chemical, oil production and refining industries, utilities and other industries. However, due to the complexity and versatility of the flow of the gas-liquid mixture in the flow part of the dynamic pump, it is difficult to accurately determine the impact of free gas on the pump characteristics. Therefore, the problem of pumping foaming, steam - and gas-saturated mixtures is the subject of constant attention of pump engineers.

The presence of free gas in the pumped medium disrupts the flow continuity and creates hydrodynamic conditions that correspond to the normal operation of the pump, and which leads to a significant reduction in its parameters (capacity $Q$, head $H$, efficiency $\eta$). The degree of influence the two-phase stream on the flow parameters in the pumps flow part and its characteristics, in general, is determined primarily by the value of the volumetric gas content:

$$\beta = \frac{q}{q+Q},$$

where $q$, $Q$ – is the volumetric flow rate of gas and liquid, respectively.

Although an important influence on the pumps parameters have: the size of the gas bubbles, the regime flow of the gas-liquid mixture in the suction pipe of the pump, the characteristics of the medium (viscosity, density, foaming ability, surface tension, etc.).

The complexity the flow of two-phase medium in the pumps flow part currently does not allow to make an accurate analytical description of the process. This depends changes in the flow density in different places of the flow part, different speeds of the gaseous and liquid phases, changes in the flow regime or structure of the flow and a range of other parameters. An attempt to theoretically describe
the process of flowing the gas-liquid medium in the flowing part of the centrifugal pump made in [1-3], but currently there are no known reliable techniques for calculating pumps performance curves running on gas-liquid mixture.

External displays changes in the characteristics curves of a dynamic pump during the transition of its operation from single-phase fluid to two-phase are similar to its operation during cavitation is observe a decrease in pump parameters, increase noise and vibration. At a certain value of the gas content is detecting a sharp decrease in pump pressure, even to the complete stopping of its operation (the same as the cavitation failure of the pump operating regime).

With increasing volume of the volumetric gas content at the inlet to the pump $\beta$ in the flow part there are gas cavities, which are constantly formed. They arise as a result of confluence gas bubbles and qualitatively change the hydrodynamic parameters of the impeller, at inlet and outlet, which leads to a violation of the kinematic similarity of the flow at different gas contents. When a certain value is reached, which is called the volumetric critical gas content $\beta_{cr}$, gas cavities that increase in size overlap the inter-blade channels of the impeller, there is a rupture of the flow continuity and the pump stops working. For a centrifugal pump, the critical gas content is within the limits $0.12 - 0.15$ [4, 5].

2. Purpose and tasks of the research
It is necessary to determine what value of the volumetric critical gas content can be achieved in the torque flow pump without separation of gas and liquid phases before pumping the gas-liquid mixture.

To achieve this purpose, the following tasks are formulated:
1. Development of a physical model of the gas-liquid mixture flow in the flow part of a torque flow pump the «Turo» type.
2. Determination the mechanisms influence of the gas component in the pumped medium on the performance curves of the torque flow pump the «Turo» type.

3. Research results

3.1. Experimental research
To analyze the effect of gas on the characteristics of the pump, convenient is to correlate the dimensionless coefficients of head $\psi$, capacity $\varphi$ and power $\mu$ to dimensionless coefficients of these parameters at the point of the maximum efficiency of the pump when pumping pure liquid. Dimensionless coefficients are defined as:

$$\psi = \frac{2 \cdot gH}{u_2^2},$$

$$\varphi = \frac{4 \cdot Q}{\pi D_2^2 u_2},$$

$$\mu = \frac{\psi \varphi}{\eta} = \frac{8 \cdot N}{\rho \pi D_2^2 u_2^2 \eta}.$$ 

where $H$ – head, m;
$u_2$ – circumferential velocity of impeller, m/s;
$Q$ – capacity, m$^3$/s;
$N$ – power (WHP), kW;
$D_2$ – impeller external diameter, m;
$\rho$ – fluid density, kg/m$^3$.

According to the test results, dimensionless coefficients were obtained at the optimal point: $\psi_0 = 0.039; \varphi_0 = 1.155; \mu_0 = 0.078$. The efficiency at the rated operating point was $\eta = 0.578$.

The characteristics of the torque flow pump at different inlet gas content $\beta$ were obtained in the region at the capacity $0.56Q, 0.75Q, Q, 1.13Q$. The amount of intake air increased until the pump flow
rate stopped (reaching the value of the critical gas content). Lines of gas constant are the performance
characteristics of the pump. The test results are shown in Figure 1.

In the "underload" regimes (at $\varphi < \varphi_0$) the pressure decrease is greater than at the rated operating
point. At $\beta = 0.40$ the difference is 25% (Fig. 1). The same picture is observed in the characteristics of
the efficiency (Fig. 2).

![Figure 1. Influence the volume gas content on the head characteristic of the pump.](image)

![Figure 2. Influence the volume gas content on the efficiency of the pump.](image)

No significant changes are observed in the power characteristic (Fig. 3). In the zone close to the optimum, the parameters at different gas contents almost fall on the power curve at $\beta = 0$.

Figure 4 shows the change in pump parameters at the rated operating point with increasing gas
content from zero to 0.45.

To the value of $\beta = 0.06 – 0.07$ there is some growth the parameters (2 – 4%) of the tested pump. Air bubbles get into the free chamber, evenly mixed with water (bubble flow structure).

At $\beta > 0.06$ the air bubble, passing the distance from the air inlet to the free chamber, begins to rise
to the top of the suction pipe, where the actual volumetric gas content begins to increase. Head and
efficiency of the pump begin to decrease sharply, thus decrease capacity of the pump is not so sharp i
at $\beta = 0.20$ is 0.92 from $\varphi_0$. The power curve changes from 0.96$\mu_0$ to 1.04$\mu_0$.

At $\beta = 0.15 – 0.20$ there is a partial phase separation and only individual bubbles get into the free
chamber together with water. In the suction pipe is observe a undulating and projectile structure of the
flow. Part of the air from the top of the suction pipe, bypassing the impeller, immediately get into the
pressure pipe.

Up to $\beta = 0.32 – 0.34$ head and efficiency do not change, and power and supply begin to increase.
With a further increase in the volume content of air in the supply, all the parameters of the pump
decreasing.

### 3.2. Theoretical research

The theoretical head generated by the impeller of a dynamic pump is determined by the Euler equation [6]

$$H_T = \frac{(u_2v_{u2} - u_1v_{u1})}{g},$$

where $u_1, u_2$ – circumferential velocities at inlet and outlet impeller in accordance, m/s;
$V_{u1}, V_{u2}$ – circumferential components of absolute velocity at inlet and outlet impeller in accordance, m/s.
Figure 3. Influence the volume gas content on the power of the pump.

From the above equation it is seen that the head does not depend on the density of the medium. The common action on the gas bubble moving in the interblade channel of the impeller of the lifting force and the frontal force, and the uneven distribution of pressure across the width of the channel leads to the lag of the gas velocity from the liquid and accumulation its in some places of the impeller. The average density of the mixture is less than in the case of pumping pure liquid [7]. The gas accumulated in the interblade channel changes the “geometry” of the impeller and, accordingly, the components of the speed triangle. In particular, this applies $V_u$ both at the inlet to the impeller and at the outlet from it.

At a certain value of the volumetric gas content, a significant gas cavity is formed at the non-working side of the blade and creates a wedge-shaped gas zone (Fig. 5). There is no increase the pressure in this zone and there is no flow rate. The gas zone reduce the effective cross section of the impeller, especially at the outlet.

The output of the gas-liquid flow from the impeller is happened on the working side of the blade with a reduced exit angle and with increasing flow speed. Meridional component $V_m$ of absolute speed $V_2$ increases with decreasing effective cross section of the impeller at the outlet. The impeller transmits energy to the medium which is pumping as kinetic energy by increasing the fluid flow speed [8]. At the outlet, at high gas content, appear new triangles of flow velocities (Fig. 6).

Figure 5. The flow of gas-liquid mixture in the channels of the impeller. Figure 6. Triangles of flow velocities at the outlet of impeller.
4. Conclusions
1. It is determined that changes in the characteristics (before the failure of the parameters) of the pump occur due to the influence of the gas factor on the operation of the impeller.
2. The influence of the gas component in the pumped medium on the performance characteristics of the torque flow pump of the “Turo” type has been experimentally investigated. It is established that for this pumps type the value of the critical gas content is equal to $\beta_{cr} \leq 0.40 - 0.45$ without additional devices for preparing the mixture.

References
[1] Yan S, Sun S, Luo X, Chen S Li C, Feng J 2020 Numerical investigation on bubble distribution of a multistage centrifugal pump based on a population balance model Energies 13 908
[2] Bagci A S, Kece M, Nava J 2010 Challenges of using electrical submersible pump (ESP) in high free gas applications Proceedings of the CPS/SPE International Oil & Gas conference and Exhibition
[3] Verde W M, Biazussi J L, Sassim N A, Bannwart A C 2017 Experimental study of gas-liquid two-phase flow patterns within centrifugal pumps impellers Exp. Therm. Fluid Sci. 85 37
[4] Neumann M, Schafer T, Bieberle A 2016 An experimental study on the gas entrainment in horizontally and vertically installed centrifugal pumps J. Fluids Eng 9 138
[5] Gulich J F 2010 Centrifugal Pumps (Berlin: Springer-Verlag)
[6] Evtushenko A 2013 Development of the theory of the working process, the practice of designing and using dynamic pumps monograph (Sumy: Sumy State University)
[7] Andrenko P, Grechka I, Khovanskyy S, Svynarenko M 2019 Experimental study of the power characteristics influence on the hydraulic efficiency Lecture Notes in Mechanical Engineering 227
[8] Korczak A, Martsynkovskyy V, Gudkov S 2012 Estimating influence of inertial resistance of throttle for hydraulic balancing device on rotor axial vibration Procedia Engineering 39 261