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TO THE QUESTION OF INCREASING THE PILOT PERFORMANCE OF THE STAGE OF THE SUBMERSIBLE CENTRIFUGAL PUMP AT THE PRODUCTION OF OIL AND GAS PRODUCTION

Проведено огляд існуючих конструкцій ступенів заглибних відцентрових насосів, досліджень і способів підвищення їх наполегливості. Описано основні причини втрат енергії в проточних частинах насосів типу ЕЦН. Проведено чисельне моделювання течії ГЖС. Визначено шляхи підвищення напористості. Отримано значення напору в рухомих і нерухомих елементах проточної частини. Запропоновано модифіковану проточна частина, що дозволяє знизити гідравлічні втрати і підвищити напористість всій ступені в цілому.

Ключові слова: ступінь, проточна частина, газорідинна суміш, гідравлічні втрати, напір, характеристики, розподіл тиску.

Проведен обзор существующих конструкций ступеней погружных центробежных насосов, исследований и способов повышения их напористости. Описаны основные причины потерь энергии в проточных частях насосов типа ЭЦН. Проведено численное моделирование течения ГЖС. Определены пути повышения напористости. Получены значения напора в подвижных и неподвижных элементах проточной части. Предложена модифицированная проточная часть, позволяющая снизить гидравлические потери и повысить напористость всей ступени в целом.

Ключевые слова: ступень, проточная часть, газожидкостная смесь, гидравлические потери, напор, характеристики, распределение давления.

A review of existing designs of stages of submersible centrifugal pumps, research and ways to increase of head. The main causes of energy losses in the flow parts of pumps of the ESP type are described. A numerical model for simulating multiphase flows has been determined. Numerical simulation of the flow of GLM is carried out. The ways of increasing the assertiveness are determined. The values of the head in the moving and stationary elements of the flow part are obtained. headlosses in submersible centrifugal pumps are analyzed. A modified flow part is proposed, which allows to reduce hydraulic losses and increase the power of the entire stage as a whole. The calculation of the modified step is carried out. The flow of the gas-liquid mixture in the modified stage is visualized. The pressure and energy characteristics of the new stage are obtained. The distribution of static pressure along the blade is shown for different gas contents.

Keywords: stage, flowing part, gas-liquid mixture, hydraulic losses, head, characteristics, distribution of pressure.

Introduction. One of the main means of mechanized oil production are installations with submersible electric multi-stage centrifugal pumps (ESP). Submersible electric centrifugal pumps by design and principle of operation do not differ from superficial pumps. However, the restrictions on the overall diametrical dimensions of the oil wells (146, 168 mm) where the pump is installed determine the specific design of the ESP and the working process in the flowing part of the pump [1]. The head of one stage of the centrifugal pump is approximately 4–6 m. Therefore, in uplift of oil and provide the necessary head (pressure), the number of stages in the ESP reaches 200–500 units.

Another feature that significantly affects the performance of ESP is the composition and parameters of the pumping oil products. In the actual conditions of operation of the ESP, the product of the pump is a mixture of reservoir oil, water and gas – the gas-liquid mixture (GLM). The presence of free gas at the inlet to the pump increases the volume of the mixture that passes through the first working stages of the pump. Part of the energy supplied to the pump shaft is expended on compressing the gas bubbles. Also, due to the presence of free gas in the liquid, in the cavities of the impellers and guiding devices, gas caverns are formed which do not participate in the energy transfer flow of the pump with the pumped liquid. Therefore, the process of flow past the blades worsens. All this leads to degradation of pump performance. Muraviev I. M., Mishchenko I. T., Lyapkov P. D., Minigazimov M. G., Drozdov A. N., Igrevsky V. I. and others engaged in the problems of the harmful effect of free gas in oil products on the performance characteristics of the pump. A large amount of experimental research was carried out by Borets Ltd, where new designs of ESP stages, as well as pre-wired devices, were proposed. Also experimental work is conducted at Sumy State University [2]. Recently, publications of a number of computational papers devoted to the numerical modeling of GLM in the channels of centrifugal pumps have appeared. These are the works of Cirilo R., Sachdeva R., Minemura K., Sun D. Mikhailov V. G. and Petrov P. V., Sapozhnikov S. V. [3].

It should be noted that the determining factor in the issue of the effect of gas on the operation of the pump is the gas content β_{in} (the ratio of gas flow to the mixture flow rate) at the pump intake.

With a high gas content at the pump inlet of more than 35 %, to reduce the harmful effect of gas on the submersible pump, the installation of gas separators, dispersants, and pre-activated multiphase pumps is used. Installation of gas separators and gas separators-dispersants, allows to divert a part of the gas entering the pump (or from the pump) into the space. However, these devices have their limitations in the application. So gas separators cannot be used in wells equipped with a packer; and gas separators-dispersants when pumping out liquids with a large number of surfactants [4]. Basically of the design of multiphase pumps (MFP) [5], an axial-type stage is adopted, which allows the maximum gas concentration at the pump inlet to be 75 %.

For oil wells with a low gas content of up to 200 m^3/m^3, when the gas content at the pump intake can be ensured up to 25 % by choosing the depth of the pump installation in the well, the use of gas separators and MFP is not economically feasible. For these conditions, the efficiency of the operation of the ESP is advisable to be achieved by increasing the centrifugal stage speed and conical assembly of the stages in the pump. In the conical assembly, the principle of the pump arrangement is used in stages of different types with different nominal feed rates, which disperses and partially compresses the GLM.

In this paper, we consider the increase in the assertiveness of the stage of normal high-speed by modifying the flow-through part of the pump ESPT5-80 in the presence of gas in the range of 10-25 %.

Information review. One of the first works to improve the design of the centrifugal stages of the ESP are the works of Bogdanov A. A. [5] and Vasilyev V. M. [6]. In these studies, experimental studies of new designs of ESP stages were carried out. Considered the using of vortex impellers, the bevel of the output edge of the impeller, the turning of the rear disc, the inclination of the impeller blades at the exit, the extension of the guide vane blades in the axial direction, and the extension of the blades of the impellers.

In the future, there are works on the use of new stage designs for oil production in complicated conditions. For example, in work [7] a combination of centrifugal and vortex stage elements is used in one product. The impeller is obtained by adding a vortex crown to the centrifugal structure. The vortex crown is located on the master disk. The guide device has a design close to the centrifugal. The geometric dimensions of the flow parts of the stage are optimized taking into account the effect of the vortex crown on the flow of the liquid. Patents were obtained for this design of the stages.

A variant of the construction of stage [8] was also proposed, where protrusions oriented in the radial direction performing the function of additional impeller blades are made on the upper surface of the driving disk of the impeller. This degree makes it possible to increase the pressure by creating additional energy by the vortex crown formed by the speeches on the covering disk.

According to the results of the information survey, it is proposed to change the meridian section of the impeller [9]. A stage with an *S*-shaped shape of the flow part of the impeller was designed to exclude the sharp turn zone between the exit from the impeller and the entrance to the guide vane. This reduces hydraulic losses and increases the pressure at the exit from the stage. To confirm the effectiveness of the adopted shape of the flow part, it is proposed to perform numerical simulation of the flow for two variants of the pump stage for a homogeneous liquid phase and for a gas-liquid mixture.

Formulation of the problem. Let's consider two variants of execution of a stage of pump ESPT5-80. The construction is shown in fig. 1, *a*, *b*.

Variant 1 – the basic stage of ESPT5-80 [9] (Fig. 1, *a*).

Variant 2 – modification of stage ESPT5-80-I with *S*-shaped meridional section (Fig. 1, *b*). A patent was obtained for this stage design [10].

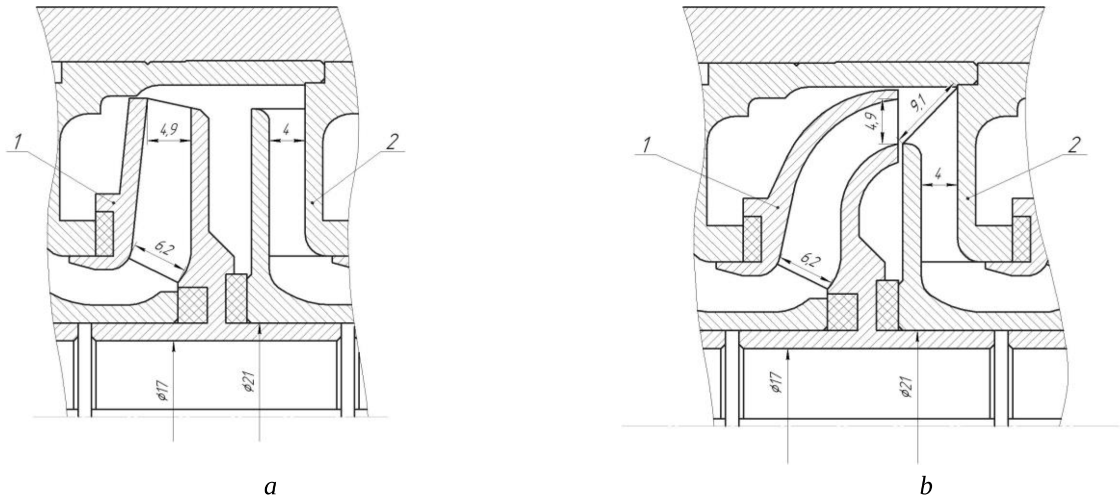


Fig. 1 – Basic (*a*) and modified (*b*) stages of the pump ECND5-80:
1 – impeller; 2 – guide vane

At the first stage, a numerical experiment was carried out, where the working medium was water. This is necessary to compare the integral characteristics of the base and modified stages. In the future, the pumped medium was taken by GLM.

To carry out a numerical study, a mathematical model (MM) of the turbulent flow of a two-phase fluid-gas flow in the formulation of Euler was chosen. Phases are considered as interpenetrating media: a continuous liquid phase and a dispersed gas phase [11, 12].

The basic equations of MM have the form:

continuity equation:

$$\frac{\partial}{\partial x_i}\left(\beta\rho u_i\right)_k = 0$$

RANS equation:

$$\frac{\partial}{\partial x_j}\left(\beta\rho u_i u_j\right)_k = -\beta\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\beta\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right]_k +$$

$$+\frac{\partial}{\partial x_j}\left(-\rho u_i^{'} u_j^{'}\right)_k \pm M_k + F_\omega,$$

where u is the average speed; u' is the turbulence rate; ρ is the density; p is the pressure; M_k is the transmission of interphase pulse (gas-liquid) per unit volume; μ is the dynamic viscosity; F_ω is the action of centrifugal and Coriolis forces; δ_{ij} is the Kronecker function.

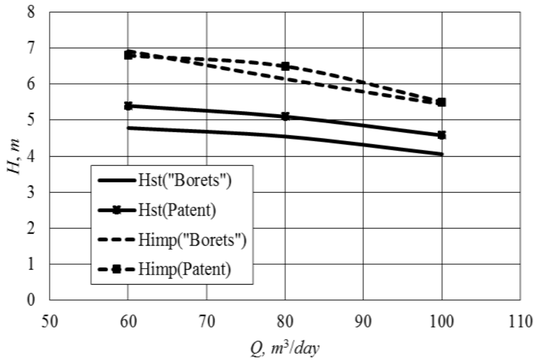
According to this model, the equations are written for each phase k ($k = 1, g$) and solved jointly. The phases are interconnected by the interphase momentum transfer.

Numerical implementation was carried out with the help of OpenFOAM open integrable platform [13].

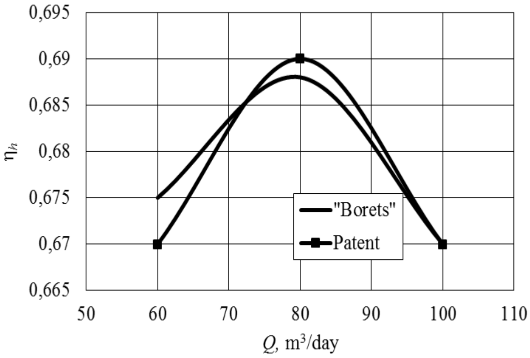
Analysis of simulation results.

1. Results of numerical simulation for a single-phase medium (water).

In fig. 2. The pressure and energy characteristics of the two stage variants under study (the basic Borets Ltd and the modified one) for single-phase liquid (water) are presented.



a



b

Fig. 2 – Comparison of the characteristics of the basic and modified stages:

a – pressure characteristic; *b* – energy characteristic

Now let us consider the element pressure created by the pump stage of ESPT5-80, namely, the impeller and the losses in the immobile areas of the flow section for ESPT5-80 (Table 1) and ESPT5-80-I (Table 2).

Table 1 – The values of the created head and losses in the stationary parts of the stage (basic variant)

Q, m^3/day	H, m	H_r, m	H_t, m	H_g, m	H_Σ, m
60	4,784	6,93	-0,618	-1,528	-2,146
80	4,547	6,154	-0,441	-1,166	-1,607
100	4,056	5,453	-1,01	-0,387	-1,397

Table 2 – The values of the created head and losses in the stationary parts of the stage (new variant)

Q, m^3/day	H, m	H_r, m	H_t, m	H_g, m	H_Σ, m
60	6,277	6,7	0	-0,423	-0,423
80	5,653	6,5	0	-0,847	-0,847
100	4,578	5,338	0	-0,76	-0,76

So, based on the obtained values, in the modified stage it is possible to get rid of the zone of sharp rotation after the liquid exit from the impeller, which positively influences the change in losses in the guiding apparatus itself.

2. Results of numerical simulation for a gas-liquid mixture (10 % gas volume flow).

A comparison of the flow structure for the two variants of the flow section for the optimum mode is shown in fig. 4.

Analysis of the flow structure showed practically no mutual influence of moving and rotating regions on each other (fig. 4, *b*), as in the usual stage (fig. 4, *a*). It is possible to pump the GLM with a large content of free gas.

In fig. 3 are graphs of the distribution of static pressure along the blade for the basic stage variant when working on water (1), on GLS (2), and modified for GLS (3). The value of the input gas content in the calculations was assumed to be β_{in} = 10 %.

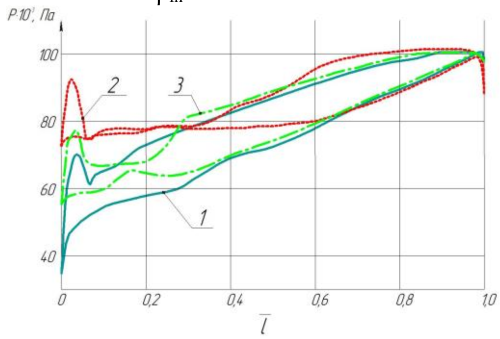
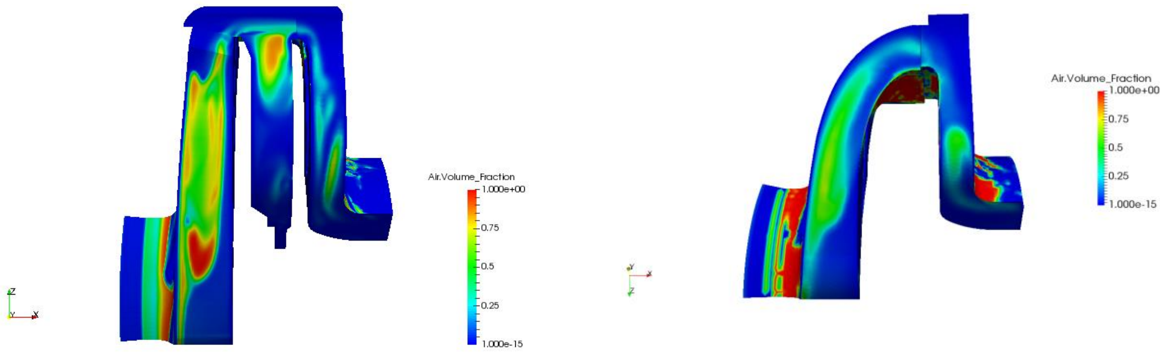


Fig. 3 – Graph of pressure distribution along the blade: 1 – basic version (water); 2 – basic variant (β_{in} = 10 %); 3 – new variant (β_{in} = 10 %)



a *b*

Fig. 4 – Structure of the GLM flow in the ESPT5-80 stage with β_{in} = 10 %:
a – the stage of "Borets" Ltd [8]; *b* – modified stage [9]

Conclusions. In view of the complex nature of the flow in the pump stage of the ESP and its low head, it becomes necessary to increase it. A review of the studies was carried out, which suggested ways to solve this.

The authors of this article considered the options for reducing hydraulic losses and proposed the following option: the most rational is the change in the meridian section of the impeller and the direct entry of the outlet to the entrance to the guiding apparatus (fig. 2) [10]. Thus, it is possible to remove the sharp turning zone, which not only eliminates losses in this element of the flowing part, but also reduces them in the guide apparatus. In this regard, there is an opportunity to increase the intensity of the stage as a whole, which positively affects the pumping of the GLC, which is the product of any oil well.

Список литературы

1. *Агеев Ш. Р.* Российские установки лопастных насосов для добычи нефти и их применение. Энциклопедический справочник. / *Ш. Р. Агеев, Е. Е. Григорян, Г. П. Макиенко.* – Пермь: ООО «Пресс-Мастер», 2007. – 645 с.
2. *Найда М. В.* Аномалії, які виникають при перекачуванні водоповітряної суміші відцентровим насосом / *М. В. Найда, Ю. Я. Ткачук //* Вісник СумДУ. Серія «Технічні науки». Суми: СумДУ, 2013. – № 4. – С. 63–69.
3. *Сапожніков С. В.* Врахування газової складової середовища, що перекачується, при визначенні конструкції та робочої характеристики динамічного насоса : автореф. дис. кан-та техн. наук : 05.05.17 / *С. В. Сапожніков*; Сумський Державний Університет. – Суми, 2002. – 18 с.
4. *Пещеренко М. П.* Повышение эффективности эксплуатации УЭЦН путем применения мультифазных насосов / *М. П. Пещеренко, О. М. Прельеман, А. И. Рабинович, А. Л. Каплан* // Бурение и нефть. – Москва: Бурнефть, 2014. – № 04. – С. 56–60.
5. *Богданов А. А.* Погружные центробежные электронасосы для добычи нефти (расчет и конструкция) / *А. А. Богданов.* – М. : Недра, 1968. – 271 с.
6. *Васильев В. М.* Совершенствование погружных нефтяных центробежных насосов : дисс. кан-та техн. наук : 05.04.03 / *В. М. Васильев*; Московский ордена трудового красного знамени институт химического машиностроения. – Москва, 1984. – 163 с.
7. *Агеев Ш. Р.* Надежные центробежные установки с малой подачей для добычи нефти в осложненных условиях / *Ш. Р. Агеев, П. Б. Куприн, В. Н. Маслов [и др.]* – Москва**:** ОКБ КОННАС, 2005. – 98 с.
8. *Шерстюк А. Н.* Ступень погружного многоступенчатого центробежного насоса / *А. Н. Шерстюк, С. М. Мешалкин, С.В. Петрова, Т.А. Ермолаева, Ю.Н. Анникова, Я.В. Матевеенко* // Патент РФ на изобретение № 2269032. – опубл. 27.01.2006.
9. Каталог продукции. ООО Производственная компания «Борец». – М., 2014, – 495 с.
10. *Шевченко Н. Г.* Ступінь заглибного насоса / *Н. Г. Шевченко, В. Е. Дранковський, О. Л. Шудрик, К. С. Рєзва* // Патент України на корисну модель № 117755. – опубл. 10.07.2017.
11. *Muller T.* Numerical 3D RANS simulation of gas-liquid flow in centrifugal pump with an Euler-Euler two-phase model and a dispersed phase distribution / *T. Muller, P. Limbach, R. Skoda* // Proceedings of 11th European Conference on Turbomachinery Fluid dynamics & Thermodynamics ETC11, March 23 - 27, 2015, Madrid, Spain.
12. *Шевченко Н. Г.* Исследование течения газожидкостной смеси в проточной части ступени погружного насоса для добычи нефти / *Н. Г. Шевченко, А. Л. Шудрик, Е. Ю. Бондаренко //* Bulletin of NTU "KhPI". Series: Hydraulic machines and hydrounits. – Kharkiv: NTU "KhPI", 2017. – № 22(1244). – P. 31–37.
13. *Shudryk A. L.* Using Open SOFTWARE Application Packages for of viscous incompressible fluid / *A. L. Shudryk //* Bulletin of NTU "KhPI". Series: Hydraulic machines and hydrounits. – Kharkiv: NTU "KhPI", 2016. – № 20(1192). – P. 53–57.

References (transliterated)

1. Ageev, Sh. R., E. E. Grigorjan and G. P. Makienko. *Rossijskie ustanovki lopastnyh nasosov dlja dobychi nefti i ih primenenie*. Perm: Press-Master, 2007. Print.
2. Nayda, M. V. and Yu. Ya. Tkachuk "Anomaliyi, yaki vinikayut pry perekachuvanni vodopovitryanoyi sumishi vidtsentrovym nasosom" *Visnyk SumDU. Ser. Tekhnichni nauky.* No. 4. Sumy: SumDU, 2013. 63–69. Print.
3. Sapozhnikov, S. V. *Vrahuvannya gazovoyi skladovoyi seredovischa, scho perekachuyrtsia, pri viznachenni konstruktsiyi ta robochoyi harakteristiki dinamichnogo nasosa. Avtoref. dys. na zdobuttia nauk. stupenia kand. tekhn. nauk.* Sumy, 2002. Print.
4. Peshcherenko, M. P., O. M. Perelman, A. I. Rabinovich and A. L. Kaplan "Povyishenie effektivnosti ekspluatatsii UETsN putem primeneniya multifaznyikh nasosov" Bureniye i neft. No. 04. Moscow: Burneft, 2014. 56–60. Print.
5. Bogdanov, A. A. *Pogruzhnye centrobezhnye jelektronasosy dlja dobychi nefti (raschet i konstrukcija).* Moscow : Nedra, 1968. Print.
6. Vasilyev, V. M. *Sovershenstvovanie pogruzhnyih neftyanyih tsentrobezhnyih nasosov. Dis. na soiskaniyt nauch. stepeni kand. tekhn. nauk.* Moscow, 1984. Print.
7. Ageev, Sh. R. et. al. *Nadezhnyie tsentrobezhnyie ustanovki s maloy podachey dlya dobyichi nefti v oslozhnennyih usloviyah*. Moscow: OKB KONNAS, 2005. Print.
8. Sherstiuk, A. N, et. al. Stupen pogruzhnogo mnogostupenchatogo tsentrobezhnogo nasosa RF Patent №. 2269032. 27 January 2006. Print.
9. *Katalog produkcii. OOO Proizvodstvennaja kompanija "Boretc"*. Moscow, 2014. Print.

10. Shevchenko, N. G., et. al. *Stupin zaglybnogo nasosa* Ukraine Patent na korysnu model' № 117755. 10 July 2017. Print.
11. Muller, T., P. Limbach and R. Skoda "Numerical 3D RANS simulation of gas-liquid flow in a centrifugal pump with an Euler-Euler two-phase model and a dispersed phase distribution" *Proceedings of 11thEuropean Conference on Turbomachinery Fluid dynamics & Thermodynamics ETC*, March 2015, Madrid, Spain. 23–27. Print.
12. Shevchenko, N. G., A. L. Shudryk and E. Yu. Bondarenko "Issledovanie techeniya gazozhidkostnoy smesi v protochnoy chasti stupeni pogruzhnogo nasosa dlya dobyichi nefti" *Bulletin of NTU "KhPI". Ser.: Hydraulic machines and hydrounits.* No. 22(1244). Kharkiv: NTU "KhPI", 2017. 31–37. Print.
13. Shudryk, A. L. "Using Open Software Application Packages for of viscous incompressible fluid" *Bulletin of NTU "KhPI". Ser.: Hydraulic machines and hydrounits.* No. 20(1192). Kharkiv: NTU "KhPI", 2016. 53–57. Print.

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