ГЕОТЕХНОЛОГИЯ. ГОРНЫЕ МАШИНЫ

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Increasing the operating time of electrical submersible pumps by using self-cleaning filters

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Abstract

Introduction. *The article considers issues relating to electrical submersible pumps (ESP) work under complicated operating conditions caused by a high content of solids in the pumped borehole fluid. Factors that cause or exacerbate these complications are also studied. The article justifies the urgency of increasing the operating time of submersible equipment under complicated operating conditions.*
Methods of research *includes analyzing engineering and process approaches to ESP protection from a detrimental effect of solid particles. Within these approaches, specific ways of protecting borehole equipment from hydroabrasive wear are considered. It is concluded that today, in terms of economic indicators and efficiency, borehole and intake filters, mainly slotted, are preferable for ESP protection. The main advantages and disadvantages of known mass-produced slotted filter designs are considered.*
Results. *The process of production tubing deformation in the course of pumping with ESP is considered and mathematically described. An engineering solution is proposed for a self-cleaning borehole slotted filter which makes it possible to eliminate the main disadvantages of slotted filters, specifically low dirt capacity and the need for tripping operations aimed at restoring the filter's permeability. The method is given for calculating the deformation of the filter element within the slotted filter as part of the ESP below ground.*
Conclusions. *The use of the described self-cleaning filter will increase the ESP operating time in wells characterized by solids circulation. Reducing trippings, and therefore the downtime of wells, during the operation of ESP with slotted filters will significantly reduce the costs of oil producing enterprises and increase oil production profitability.*

Keywords: *electric submersible pump; ESP; hydroabrasive wear; self-cleaning borehole slotted filter.*

Introduction. More than 80% of oil in the Russia and CIS fields is produced using electric submersible pumps (ESP), and about 60% of oil production wells operate with the use of ESPs [1–3].

A large amount of wells with ESP are classified as complicated, which increases the accident rate of borehole pumping equipment. Failures of ESP elements make tripping necessary, which is accompanied by high material and time expenditures and significantly reduce the profitability of oil production and hence the profit of the mining enterprise [4, 5].

One of the main factors complicating oil recovery by the mechanized method is the presence of solid particles in the recovered borehole fluid. This factor negatively affects ESP operation due to the development of intense hydroabrasive wear and clogging of the flow channels of electric submersible pump stages. In the Ural and Western Siberia oil fields, the presence of solids in borehole fluid is the cause of up to 30% of ESP failures [6–8].

The current technology of hydraulic fracturing (HF) significantly affects the growth of submersible equipment emergency failures due to hydroabrasive wear. After HF application, the concentration of solid particles in fluid from the borehole newly put into operation increases many times. Up to 67% of the solid particles are loose proppant particles [9, 10]. Under such conditions, ESP operating time is reduced to several days.

It follows from the above that search for and development of process and engineering solutions aimed at increasing ESP operating time under an increased content of solid particles in the pumped borehole fluid is a relevant task, and its solution results are of scientific and practical interest.

Analyzing methods of ESP protection against hydroabrasive wear. Methods of protecting ESP when operating under a high content of solid particles in the produced fluid are usually divided into process and engineering methods.

Process methods include measures for limiting the borehole fluid withdrawal from production wells, cutting ESP operation in intermittent duty, and reducing the intensity of reservoir pressure maintenance systems operation. Attention is also paid to the physicochemical properties of fluids injected into the well and reservoir during various processes. The main disadvantages of the process methods are reduced deliverability of production wells, the complexity of the use, and cost [1, 11, 12].

Engineering methods of ESP protection from the negative impact of solid particles in the borehole fluid include submersible pumps and wear-resistant equipment, as well as front-end equipment as part of the ESP, namely solids separators and filters.

Wear-resistant equipment and submersible pumps are characterized by high surface hardness of the working stage flow parts, which is achieved through the use of wear-resistant materials and special processing methods. ESP hydroabrasive wear resistance is also increased by improving the design and material of seals. The main disadvantage of ESP wear-resistant design is the high cost of pumping units, which is 1.5–2 times higher than the cost of conventional units [13, 14].

The front-end equipment as part of the ESP purifies the pumped borehole fluid from solids. This equipment must provide minimum hydraulic resistance at the intake to submersible pumps under long-term efficient operation.

As part of ESP, separators for solid particles are installed under submersible electric motors (SEM). Solid particles are separated from the borehole fluid under the effect of gravitational and (or) centrifugal forces. Inconsistent efficiency of solids separation is a common disadvantage of solids separators. The separation coefficient depends on many factors, such as the well flow rate, reservoir fluid properties, and solid particles contained in it.

There are two types of ESP filters: surface action filters, which include slotted or wire-wrapped filters, and depth filters represented by filters with porous, disc, or fibrous filter elements.

Filters efficiency is much less affected by borehole conditions than by solids separators. Slotted ESP filters characterized by simple design, high maintainability and low cost, have currently become most widespread [5, 15, 16].

The main disadvantage of the filters is their low dirt capacity. As a result, they become clogged quickly, leading to pump supply failure and ESP failure. The existing methods for filter cleaning and regeneration under borehole conditions are inefficient, complex and expensive, which limit their application. In practice, filter clogging requires an ESP tripping to replace or clean the filter (unless the filter is equipped with a check valve). When the filter check valve is opened, the pumped liquid bypasses the clogged filter element. However, in this case, the hydroabrasive mixture, which is not cleaned from solids, enters the pump, leading to wear and clogging of ESP working stages [13, 14].

Engineering solutions for increasing ESP operating time when recovering oil with a high content of solids. The authors and JSC Novomet-Perm specialists proposed the design of a self-cleaning slotted ESP filter (Figure 1) [17].

Production tubing *1* within the slotted filter contains filtering section *4* where perforation in the form of through holes *7* is made and reinforcing ribs *3* are installed on the exterior surface. At the ends around production tubing *1*, the upper *2* and lower *16* dead stops in the form of buckets are mounted. There are annular gaps between the interior surface of dead stop walls and the exterior surface of production tubing *1*. A deformable filter element *8* is concentrically installed around production tubing *1*. The filter element is made in the form of wire *5* wound in a spiral, between the turns of which slots *6* are formed. A deformable filter element *8* is installed between the upper dead stop *2* and the movable double-sided stop *13*. The end turns of spiral wire *5* of filter element *8* inside the annular gaps are rigidly connected to stops *2* and *13*.

Double-sided movable stop *13* moves axially along production tubing *1* along restricting grooves *12* into which the ends of screws *11* are sunk. On the side surface of the double-sided movable stop *13*, an elastic element is fixed with screws *11*. The elastic element is made in the form of cup *10* with through holes *9*.

Cup *10* is in contact with the walls of production string *15* in the well. Between the lower dead stop *16* and the two-sided movable stop *13*, supported on their annular platforms, there is spring *14*, the force of which exceeds the elastic deformation of the wire of filter element *8*.

The slotted filter as part of the submersible pumping unit is lowered into the well. The borehole fluid with solids freely enters the surface of filter element *8* through the through holes *9* of cup *10*. Passing between slots *6* of the spirally wound wire *5* turns of filter element *8*, the borehole fluid is cleaned. Through holes *7* of filtering section *4* the fluid is fed into production tubing *1* and rises to the borehole pump (not shown in Figure 1). Solid particles, separated from the borehole fluid, settle on the exterior surface of filter element *8*, creating "bridges" of deposits and reducing its permeability (throughput) over time.

Filter element *8* is cleaned periodically due to the deformation of the production tubing, on which the ESP is suspended in the well, by changing the pressure at the wellhead.

It is known that the production tubing is deformed by the Δ value when it is filled with liquid and when the excess wellhead pressure P_{wellhead}, atm, is created. The Δ value is calculated using the formula below:

$$\Delta = \frac{10^{-4} L^2}{2E}\left[\gamma - 2\gamma_{\text{fluid}}\left(1-\mu\right)\right] + \frac{\left(1-2\mu\right) F_{\text{fa}} L P_{\text{wellhead}}}{0{,}1 EF}, \qquad (1)$$

where Δ is the value of production tubing deformation, m; L is production tubing length, m; E is the modulus of elasticity of production tubing material, MPa; γ is the specific

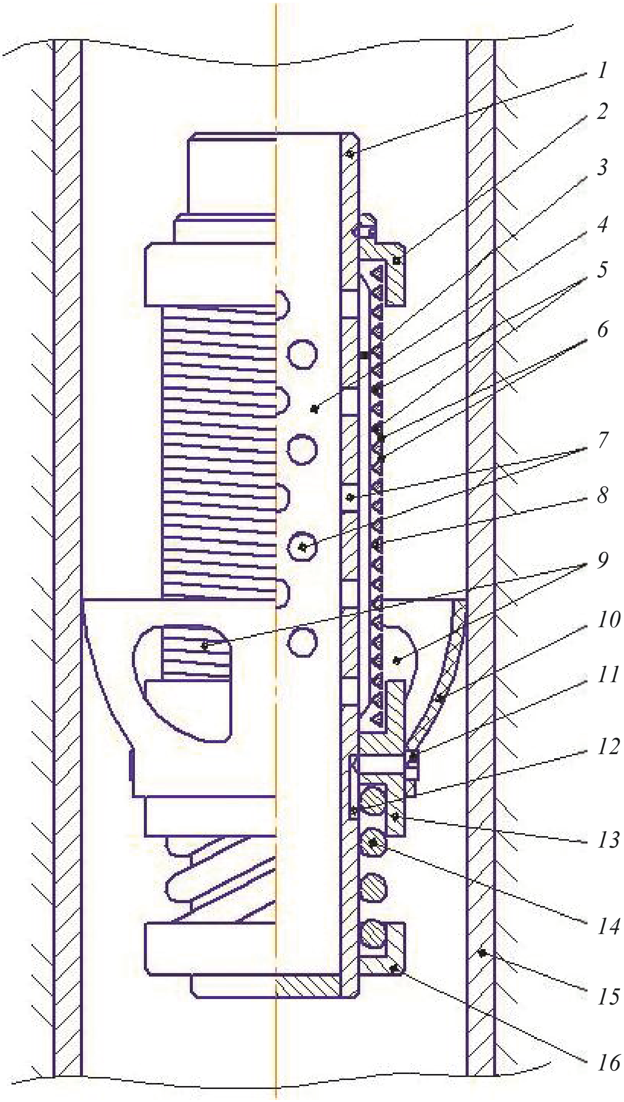

Figure 1. Schematic diagram of a slotted self-cleaning filter with a deformable filter element: *1* – production tubing; *2*, *16* – dead stops; *3* – reinforcing ribs of the filter element; *4* – filtering section; *5* – wire; *6* – slots of the filter element; *7* – perforation; *8* – deformable filter element; *9* – cup holes; *10* – cup; *11* – screw; *12* – restricting groove; *13* – movable stop; *14* – spring; *15* – production string

Рисунок 1. Принципиальная схема скважинного щелевого самоочищающегося фильтра с деформируемым фильтроэлементом: *1* – насосно-компрессорные трубы (НКТ); *2*, *16* – неподвижные упоры; *3* – ребра жесткости фильтр-элемента; *4* – фильтровальный участок; *5* – проволока; *6* – щелевые каналы фильтрующего элемента; *7* – перфорация; *8* – деформируемый фильтрующий элемент; *9* – отверстия манжеты; *10* – манжета; *11* – винт; *12* – ограничительный паз; *13* – подвижный упор; *14* – силовая пружина; *15* – эксплуатационная колонна weight of production tubing, N/m^3; γ_{fluid} is the specific weight of fluid in the production tubing, N/m^3; μ is Poisson's ratio of production tubing material; F_{fa} is the flow area of the pipe, m^2; F is the area of the annular cross-section of production tubing, m^2 (*RD 39-1-306-79. Instruction on production tubing calculation. Compiled by: A. E. Saroian, S. A. Ulanova, V. I. Belotserkovskii, V. F. Kuznetsov, V. N. Pchelkin; All-Union Scientific Research Institute for the Development and Operation of Oil Country Tubular Goods, Kuybyshev, 1980. 84 p.*).

When the value of wellhead pressure changes ($P_{wellhead}$ = var) with a filled production tubing, the left side of expression (1) is a constant value, i.e.:

$$\frac{10^{-4} L^2}{2E}\left[\gamma - 2\gamma_{fluid}\left(1-\mu\right)\right] = \text{const.}$$

Thus, the value of Δ deformation under varying $P_{wellhead}$ is determined by the expression

$$\Delta = \frac{\left(1-2\mu\right) F_{fa} L P_{wellhead}}{0{,}1EF}. \tag{2}$$

Let's make a calculation according to formula (2) for the following conditions: the production tubing consists of pipes with an exterior diameter of 73 mm and a wall thickness of 5.5 mm; pipe material is steel 30XMA (foreign analogues are 25CrMo4, 34CrMo4); elasticity modulus of pipe material $E = 2.12 \cdot 10^5$ MPa; Poisson's ratio μ = 0.3; string length L = 1000 m; the flow area of the pipes $F_{fa} = 30.2 \cdot 10^{-6}$ m^2; annular cross-sectional area of production tubing, $F = 11.7 \cdot 10^{-6}$ m^2. When the excess pressure at the wellhead $P_{wellhead}$ changes from 0 to 50 atm, the value of the production tubing deformation will be Δ = 0.024 m.

Thus, under increased pressure at the wellhead $P_{wellhead}$ = 50 atm and the production tubing length L = 1000 m, the submersible pumping unit with a slotted filter is moved (sunk) along the production tubing by Δ = 0.024 m. Pumping unit shutdown and pressure relief at the wellhead to $P_{wellhead}$ = 0 atm causes the assembly to rise along the production tubing by the same value Δ = 0.024 m, while cup 10 is in contact with the walls of the string *15* (Figure 1). This causes a short-term stretching of the deformable filter element *8*, an increase in the size of slots *6*, the destruction of the "bridges" of solid deposits and the restoration of the filter element *8* permeability. Spring *14* then presses movable stop *13* and cup *10*, which causes the restoration of the original dimensions of slots *6* and filter element *8*.

Thus, periodic mechanical cleaning of the filter element increases the operating time of the slotted filter in the well and the operating time of the ESP.

Conclusions. The article considers and analyzes the ways of protecting well pumps from clogging and hydroabrasive wear under conditions of high concentration of solids in the borehole fluid. The simplest, most common and cost-effective way to protect submersible well pumps is to use filters. However, the time of their effective operation is limited by the low dirt capacity of the filter elements. The authors propose a solution to the problem of increasing ESP operating time in wells complicated by the intense circulation of solid particles. The solution is a self-cleaning filter. The ability to self-clean the filter makes it possible to return the ESP to operation in a short period of time without tripping, which results in increased profitability of oil recovery and increased profits of oil companies.

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Повышение наработки скважинных электроцентробежных насосов за счет применения самоочищающихся фильтров

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Реферат

Введение. *Рассмотрены вопросы, связанные с эксплуатацией установок электроцентробежных насосов (УЭЦН) в условиях, осложненных высоким содержанием механических примесей в перекачиваемой скважинной жидкости, а также факторы, вызывающие или усугубляющие эти осложнения. Обоснована актуальность задачи по повышению наработки погружного оборудования в осложненных условиях эксплуатации.*
Методология исследования. *Проанализированы технический и технологический подходы к защите УЭЦН от вредного воздействия частиц механических примесей. В рамках этих подходов рассмотрены конкретные способы защиты скважинного оборудования от гидроабразивного износа. Сделан вывод о том, что на сегодняшний день с точки зрения экономических показателей и эффективности предпочтительным является способ защиты УЭЦН, заключающийся в применении скважинных и входных фильтров преимущественно щелевого типа. Рассмотрены основные преимущества и недостатки известных серийно выпускаемых конструкций щелевых фильтров.*
Результаты. *Рассмотрен и математически описан процесс деформации колонны насосно-компрессорных труб при эксплуатации скважин с помощью УЭЦН, предложено техническое решение самоочищающегося скважинного щелевого фильтра, позволяющее устранить основные недостатки щелевых фильтров – низкую грязеемкость и необходимость проведения спуско-подъемных операций для восстановления проницаемости фильтра. Приведена методика расчета деформации фильтроэлемента щелевого фильтра в составе УЭЦН, находящейся в скважине.*
Выводы. *Применение описанного самоочищающегося фильтра позволит повысить наработку УЭЦН в скважинах, характеризующихся выносом частиц механических примесей. Уменьшение количества спускоподъемных операций при эксплуатации УЭЦН, оснащенных щелевыми фильтрами, и, соответственно, простоев скважин, существенно снизит издержки нефтедобывающих предприятий и повысит рентабельность добычи нефти.*

Ключевые слова: *электроцентробежный насос; УЭЦН; гидроабразивный износ; самоочищающийся скважинный щелевой фильтр.*

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