Influence of Produced Fluid Parameters on the Use of Separator as a Component of an Electric Plunger Pump Unit

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Abstract. The article discusses the use of separators of mechanical impurities in linear electric plunger submersible pumps units in oil wells. The advantages of these units and their area of application are highlighted. The diagram and description of the bench for conducting researches on the study of submersible unit assembly of the electric plunger pump together with a separator of gas and mechanical impurities are shown. Formulas and results of calculating the settling rate of particles of different diameters are presented. The main dependences of the change in the settling rate of particles depending on the viscosity of the liquid have been determined.

1. Introduction

The largest oil and gas fields in Russia, discovered in the 60s-70s of the 20th century, are now significantly depleted. Oil production from the formations of these fields with existing technologies requires high energy costs.

In addition, the amount of explored reserves according to the classification of Russian Federation (ABC1 categories) is equal to 18 billion tons, two thirds (12 billion tons) of which are classified as hard-to-recover reserves [1]. The deterioration of the structure of oil reserves leads to an increase in the share of artificial lift, a decrease in production rates and an occurrence of complications during oil production equipment performance.

Currently, the main method of oil production is the use of electrical submersible pump unit (ESP). With the help of them, 81% of the total oil production volume oil is extracted to the surface [2].

In recent years, the share of marginal wells has been steadily increasing in the structure of the mechanized stock. Its operating time is lower than that of an average and high rate stock. It is related to the fact that ESPs in such wells operate at the boundaries of the left zone of pressure-flow characteristic with low efficiency factor. Therein a heating of the liquid above the pump intake occurs and resource of decrease of the submersible unit electrical component is observed. One of the ways to solve the problem of exploitation of marginal well stock is to search for alternative equipment to replace electric centrifugal pump units [3].

To date, the main methods of artificial lift of oil from a marginal well stock are:

- Application sucker-rod pumps unit.
- Use of low flow ESP (up to 30 m³/day).
- Application of ESP in periodical regime.
- Use of electric screw pump and sucker rod screw pump units.
For marginal wells, the traditional and widespread type of artificial lift is the installation of sucker rod pumps. About 60% of the operating oil well stock is equipped with it in the Russian Federation. The share of marginal well stock using low-flow ESP is equal to 17%, ESP in periodic regime - 20%, electric screw pump - 3% [4].

An alternative technical solution can be the use of linear submersible electric plunger pump units that combine the advantages of ESP units and plunger pumps (Figure 1).

In the linear submersible electric plunger pump units, the minimum specific quantity of metal and the ease of operation are combined with the high efficiency of the pump and independence of the pressure from the flow. It makes it possible to work in wells with a liquid flow rate of up to 30 m$^3$/day, and significantly reduces the loss of electrical energy.

The use of electric plunger pumping units leads to an increase in oil production from marginal wells. This is possible by creating a constant differential pressure drawdown and maintaining the optimal dynamic fluid level in the well [5-13].

However, complications such as mechanical impurities, high gas content, high viscosity of the emulsions formed in the well, salt deposits, etc. often occur during the operation of submersible downhole equipment [14].

An effective way to reduce the harmful effects of gas and mechanical impurities is the use of separators [4, 15 et al]. Separators extract the widest particle size range and are less susceptible to clogging. That makes this type of equipment the most promising for protecting downhole equipment. The choice of the used separator depends on the properties of the produced product and technological parameters of the operating well.

2. **Materials and methods**

To identify the features of the use of separators, by taking into account the properties of the produced product, an analysis of the study of downhole gas separators and mechanical admixtures was carried out, as well as an hydraulic calculation of the test bench to study the effect of mechanical impurities and gas on submersible electric plunger pump units components.
A number of studies have been carried out on the influence of various factors, such as the separator design, liquid flow rate, particle size, liquid viscosity, presence of free gas at the inlet to the separator, on the efficiency of separators of mechanical admixtures [16-20].

A feature of the operation of plunger pumps is the cyclical supply of liquid, which leads to a periodic liquid flow in the separator of mechanical impurities. Therefore, when designing separators of mechanical admixtures, it is necessary to consider the influence of operating parameters of the unit such as the stroke length and law movement of the plunger.

In the carried study, a test bench shown in Figure 2 was developed.

In this experimental test bench, the pump (1) drives water in the test bench in a cyclic mode, which creates conditions for liquid to pass through the separator and the plunger pump. The operating mode of the pump (1) is regulated by the installed frequency converter (11). The tank (8) is pre-filled with water from the water supply line. The liquid is pumped from the tank (8) into the suction chamber of the ejector (2). In the ejector (2), a mixture is formed with the incoming gas from the atmosphere (through the gas flow meter 10 and the check valve 9), or with the added mechanical impurities (from the tank 5 through a batch meter 6). Typical sizes of proppant and sand (most common in technological works) were used as model mechanical impurities. Then the liquid drives to one of the objects under study.

![Figure 2](image_url)

**Figure 2.** Schematic diagram of the test bench for studying the effect of increased content of mechanical impurities and gas on the operation of the components of linear submersible electric plunger pump units.

The objects of the test bench under study are:

- valve assembly of the plunger pump, cylinder and pump plunger (shortened models) (12);
- separator of mechanical impurities for plunger pumps (13);
- gas separator for plunger pumps (14).

After driving through the gas separator (14), the separated gas is removed from the column. The flow rate of the separated gas, injected liquid and gas is measured by installed flowmeters. The pressure and temperature are recorded by pressure and temperature sensors, respectively.

3. **Discussion**

The main parameters of the extracted products that affect the selection of the separator are the flow rate, viscosity, content and size of mechanical impurities.
In works [4, 19, 20] the methods that allow to simulate the process of settling of solid particles of a certain size are presented. Table 1 shows the formulas for calculating the settling rate of particles.

Table 1. Formulas for determining the particle settling rate.

| Formulas | Fluid flow regime |
|----------|------------------|
| \[ \vartheta = \frac{2r^2}{9\mu} \cdot (\rho_p - \rho_f) \cdot g \] | laminar (Stokes’ equation) |
| \[ 51.53 \cdot r \cdot \frac{\rho_f}{\mu} \cdot \sqrt{\frac{\rho_p - \rho_f}{\rho_f}} \] | transition (Allen’s equation) |
| \[ \vartheta = 62.64 \cdot r \cdot \sqrt{\frac{\rho_p - \rho_f}{\rho_f}} \] | turbulent (Rittinger’s equation) |

where: \( r \) – particle radius; \( \rho_p \) – particle density; \( \rho_f \) - fluid density; \( \mu \) – dynamic viscosity of the fluid.

The results of settling rate calculation for different sizes particles are shown in Figure 3 and 4. In the calculations, it is assumed that the sand particles are spherical.

**Figure 3.**
Diagram of particles settling rate at different flow regime and particle radius (fluid viscosity \( \mu = 1 \ mPa \cdot s \)).

**Figure 4.** Effect of viscosity on settling rate: I - fluid viscosity \( \mu = 1 \ mPa \cdot s \); II - fluid viscosity \( \mu = 10 \ mPa \cdot s \) (1, 3 – laminar regime, 2, 4 - transition regime).
Based on the plunger pump operation principle, settling of particles in the separator of mechanical impurities occurs during the injection stroke.

In a short pumping cycle, the particle will cover a small distance. The smaller the particle size is, the smaller is its path. An increase in viscosity will lead to a decrease in the particle settling rate, which will also decrease the particle settling path during the injection stroke.

Let us assume that the injection stroke takes 4 s. Then, during the pumping cycle, a particle with a radius of 100 μm in a laminar mode of water movement will overcome a path equal to 144 mm, with a radius of 300 μm - 1296 mm, with a radius of 500 μm - 3596 mm. If we consider the conditions of motion in a liquid similar in properties to low-viscosity oil, we get 15 mm path for a particle with a radius of 100 μm, 128 mm for a particle with a radius of 300 μm, and 360 mm for a particle with a radius of 500 μm.

With the same injection stroke and turbulent regime movement of water, the following data can be obtained: for a particle with a radius of 100 μm - 32 mm path, for a particle with a radius of 300 μm - 151 mm, for a particle with a radius of 500 μm - 160 mm. Formula 3 (Table 1) does not take into account the change in viscosity, but it can be assumed that an increase in viscosity during experimental studies will also negatively affect the settling rate.

Thus, the linear dimensions of the submersible separator and the properties of the produced product play an important role for effective separation.

4. Results
Calculations of the settling rate make it possible to evaluate the importance of separator linear dimensions for efficient separation of solids. Taking into account the cyclical nature of the process of pumping liquid into the plunger pump, a model of particle settling can be created. In addition to pumping dynamics and particle size, product viscosity must be considered. An increasing in the viscosity will reduce the settling rate.

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Acknowledgments
The publication has been prepared with the support of the «RUDN University Program 5-100». 