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Simulation of Fluid Movement Through a Gravel Filter

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***Abstract* – Many oil companies have serious difficulties with complicating factors as the appearance of mechanical impurities in the production of wells, the deposition of asphalt-resin-paraffin substances (ARPSs) on the equipment walls, salt deposition, and corrosion of metals. The presence of mechanical impurities ranks first in emergency stops of pumping equipment. Mechanical impurities cause wear on equipments and pump jammings. In most cases, solid scaled particles (SSPs) cause metal corrosion and ARPS precipitation. Filtering devices are described. They are designed for a specific concentration of SSPs, which do not always protect pumps at higher concentrations. Therefore, work is underway to explore the possibilities of gravel filters. Learning is important. This article discusses the use of equations known in filtering theory to determine the parameters for the movement of liquids through a gravel filter used in the oil industry to clean up mined products. Conducted analytical studies and calculations to determine the speed of movement of flows through the packing of gravel filters. The selection of new boundary conditions, slightly different from the exact, simplifies the solution of the resulting differential equations, and an increase in the calculated parameters by 5-10% (Howe method) eliminates the probability of error. Thus, the obtained values of the filtering parameters allow correctly choose the size and geometry of the filter elements.**

Keywords* – *filtration flows, differential equations, boundary conditions, weighted average potential, geometry of filter elements, mechanical impurities.

I. Introduction

During the operation of wells, sooner or later we have to deal with such phenomena as the appearance in the production of mechanical impurities, deposits on the surface of the equipment of salts, corrosion products, paraffin, various resins and asphaltenes, hydrates. All these factors complicate the process of mining and increase production costs [1].

The removal of mechanical impurities with oil takes place in many oil-producing regions of Russia and foreign countries [2, 3].

The negative impact of sand and other solid particles on the process is that they, accumulating around the well, make it difficult to filter formation fluids. Very often, in the well itself, also in the presence of mechanical impurities in the production, sand plugs are formed, which impede the production process and sometimes lead to a complete stop of work. In addition, mechanical impurities, being an abrasive material, abrade the walls of the equipment used, significantly reduce the life of submersible pumps, lifting pipes, etc.

Reduction of the period between repairs of fixed assets, repair or purchase of new equipment contributes to an increase in the cost of oil produced and a decrease in the profitability of production [4].

II. Main body

Gravel filters are used in the operation of loose and unstable reservoirs - reservoirs to protect downhole and surface equipment from abrasive wear and seizure. Consider the mechanism for creating a gravel filter, which is an element of the bottom of a production well. ho

First, the well is drilled to the top of the productive formation and cemented. In the interval of the productive formation, the penetration is carried out with a chisel of a smaller diameter, then this section is expanded with the help of chisels - expanders. The filter-frame (Figure 1), the inner part of which is directly connected to the tubing or tubing (PC), goes down into the expanded space and centers. Alluvium of gravel (graded quartz sand) into the space between the filter frame and the rock is conducted through tubing or PC.

In the operation of wells, the probability of sanding, which is quite high, various types of filters are used: frame-bar, annular, perforated, gravel and others. The purpose of filtering devices is to protect pumping and other downhole equipment from abrasive wear and seizing, as well as to increase its overhaul period [5].

In practice, the use of gravel filters achieved significant results in many sectors of the economy. In the petroleum industry, where the use of filtering d the operation of unstable or poorly stable reservoirs, there are a enough documentary materials testifying to the effectiveness of their use (Polubarinova-Kochina, 1977, Tarasov, 2007). In many oil companies and design insti improve gravel filters and create new modifications of such devices and units. Currently, gravel filters are widely used to reduce the flow of sand into an inclined or horizontal well, which are somewhat different from the same devices in vertical wells (Figure 2). It should be noted that when creating an expanded space in the horizontal part of the well, the probability of rock collapse is quite high. To prevent such collapses, special anchoring compositions are used (LINK, various resinous liquids, etc.). After that, with the help of expander bits, the process of wellbore expansion is started. Here, too, a carcass descends into the expanded space - a frame that has a guiding conical plug and more rigid plate centralities.

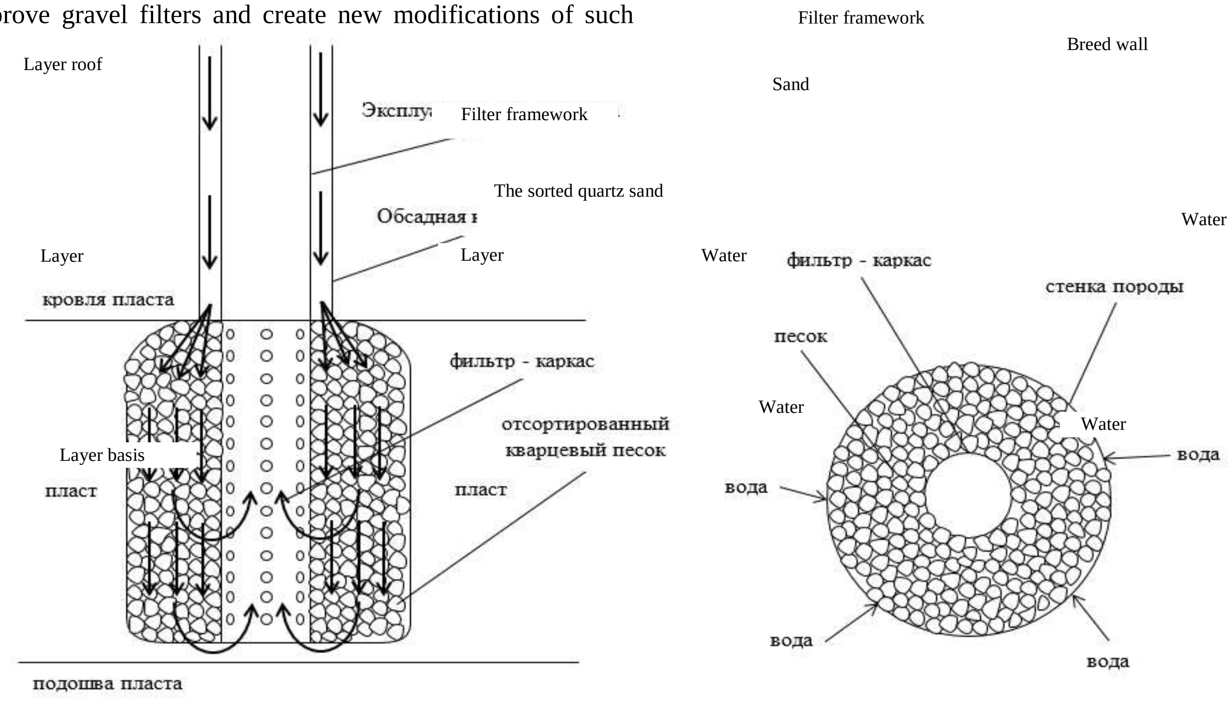


Fig. 1. Gravel filter - bottom hole design element
a) a view in a vertical plane; b) cross-sectional view

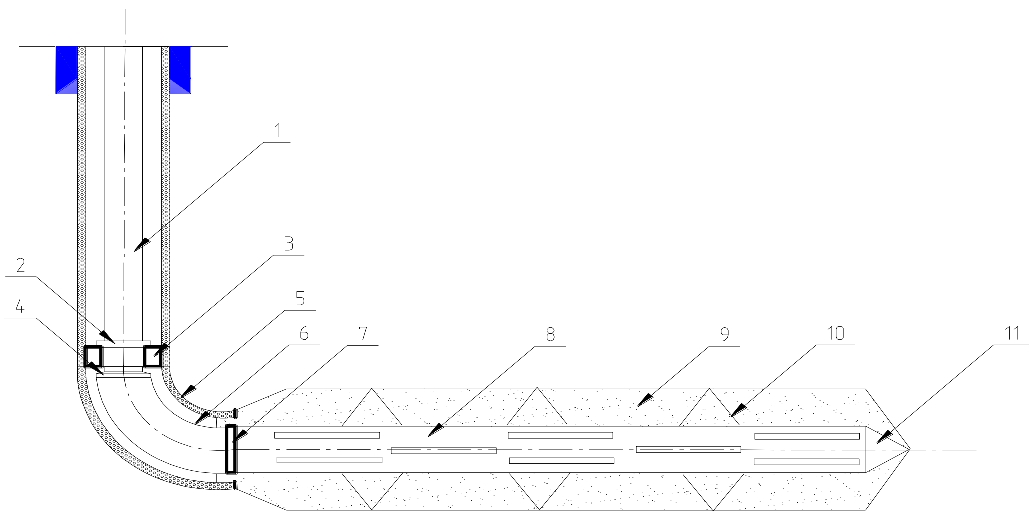


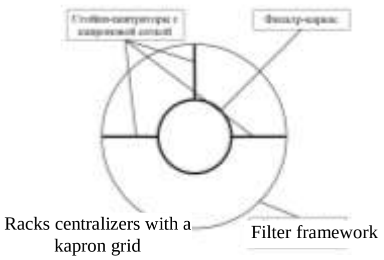
Fig. 2. Layout of gravel pack in the horizontal well completion site: 1 - lift pipe (tubing); 2 - the sub between the elevator and the fixing device (when pumping gravel fluid - an anchor, while mining - a packer device); 3 - packer (anchor); 4 - sub between packer (anchor) and tubing; 5 - casing; 6 - tubing; 7 - coupling between the tubing and the filter frame; 8 - filter frame (filter); 9 - gravel packing; 10 - centering devices (spring strips); 11- guide head (shoe)

However, it is not always possible to completely fill the space with gravel (sorted quartz sand). The oil companies of Canada, Norway and the United States are considered advanced in the use of gravel filters in horizontal wells [6]. However, they failed to completely sand the horizontal filters.

In Russia, the construction of horizontal wells, which would include gravel filters placed in the completion unit, is rarely encountered.

In this regard, the authors propose to divide the space for the washing of the quartz sand into sectors using the membranes of nylon. Then skim the resulting sector alternately, starting with the bottom. The laboratory tests showed good results.

a)



b

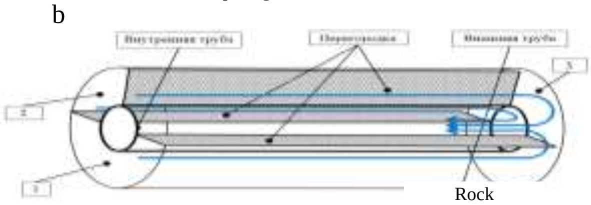


Fig. 3. Partitions for the washing of gravel (sorted quartz sand): a) general view of the) partit

Figure 3 shows the general scheme of separation of the annular space between the filter-frame and the rock. For the experiment, two glass tubes were placed concentrically. The inner tube was provided with membranes from nylon, as shown in Figure 3b. Moreover, the inner tube with its end does not rest on the bottom (plug) of the outer tube, forming a gap slightly less than the average size of the pumped sand. The process of pumping water with sand through these horizontal pipes proceeded as follows: water with sand moved along the annular space in the direction of the partitions. The sand settled more in the lower compartment, a little less in the top two. After filling the lower compartment, the upper ones were gradually filled. Purified sand water moved back through the inner tube.

In real conditions, when creating such a gravel filter, difficulties may be encountered related to the delivery of kapron partitions into the annular space. One of the solutions to this technical problem may be the attachment of the nylon to the centralizers, which are in a compressed state during the delivery of the filter cage to the expanded space. As soon as the filter frame is in place, the centralizers will disperse, revealing the nylon material and centering the filter frame.

In this paper, we also carried out studies on the filtration of a suspension-containing fluid through a gravel pack (sorted quartz sand), which we regard as a coarse-grained medium.

To solve practical problems of calculating filtration flows in a well, a single method used for all types of filter designs, called the weighted average potential method (TWAP) [7, 8], known in the technical literature as the Howe method [9]. Using this method, they always get the value of debit underestimated by 5-10%. Therefore, it is enough to increase the result obtained by 7% to get as close as possible to the exact well flow rate.

To study laminar flow through sorted quartz sand, the grains of sand are assumed to be identical and spherical, it is necessary to solve the Navier-Stokes equation

$$\frac{\partial \vec{V}}{\partial t} + (\vec{V}\nabla)\vec{V} = \frac{1}{\rho} grad(p) + \nu\Delta \vec{V}, \quad (1)$$

where $\vec{V}$ is the flow velocity vector, t is time, ρ is the density, υ is the viscosity of the fluid, p is the pressure.

To get closer to the problem of studying a problem, we consider not a real physical flow of a viscous fluid between particles of a cellular medium (gravel), but some imaginary averaged flow. The relationship between the real flow rates of $\vec{V}_{phys.}$ and filtration $\vec{V}$ will be determined as follows:

$$\vec{V}_{phys.} = \frac{1}{m}\vec{V} \quad (2)$$

where m is the porosity that is the same for isotropic media with transparency.

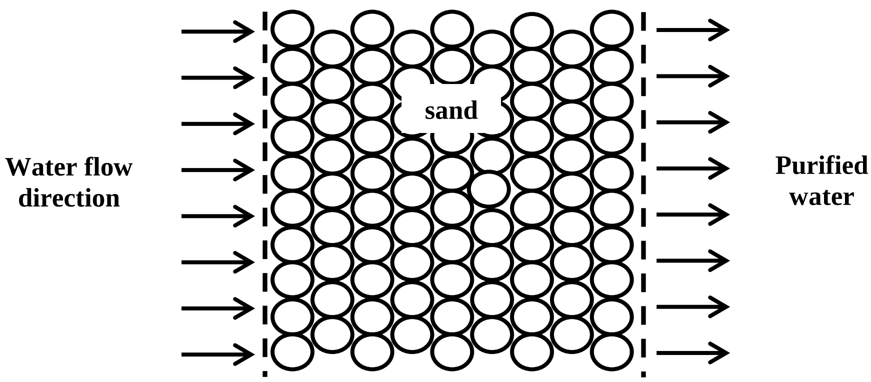


Fig. 4. The gravel wall of the filter through which the suspended liquid passes into the inner frame part.

In the theory of filtering, the term $\frac{\partial \vec{V}}{\partial t}$ from the Navier-Stokes equation is neglected [10]. In this case, this addendum is not discarded. Another expression $\nu\Delta\vec{V}$ according to the hypothesis of N.E. Zhukovsky has mass viscous friction forces acting from the skeleton of a gravel medium on a liquid.

$$\vec{F}_{fr} = -\frac{V}{k} f(V) \cdot \vec{V}, \tag{3}$$

where k is the permeability coefficient, f(V) is a certain function determined experimentally.

Replace in (1) $\nu\Delta\vec{V}$ on $F_{тр}$. and we obtain an equation that can be applied to the study of filtration processes in coarse media:

$$\frac{\partial \vec{V}}{\partial t} + (V\nabla)\vec{V} = \overleftarrow{F} - \frac{1}{\rho} grad(p) - \frac{V}{k} f(V) \cdot \vec{V} \tag{4}$$

Applying a known transformation

$$(V\nabla)\vec{V} = \vec{\omega} \times \vec{V} + grad\left(\frac{V^2}{2}\right), \tag{5}$$

where $\vec{\omega} = rot\vec{V}$, equation (4) is written in the form of Lomba-Gromeka:

$$\frac{\partial \vec{V}}{\partial t} + grad\left(\frac{V^2}{2}\right) + \vec{\omega} \times \vec{V} = \overleftarrow{F} - \frac{1}{\rho} grad(p) - \frac{V}{k} f(V) \cdot \vec{V}, \tag{6}$$

For an incompressible fluid, consider the continuity level:

$$\operatorname{div} \vec{V} = 0, \tag{7}$$

Obviously, the porous medium under consideration is isotropic, $\vec{F}_{тр.} = -\frac{V}{k}\vec{V}$, к = const., the flow is steady $\left(\frac{\partial \vec{V}}{\partial t} = 0\right)$, potential,

$$\vec{V} = grad\varphi, \tag{8}$$

the fluid is incompressible (ρ = const.), mass forces $\vec{F} = -grad(gz)$, since the Z axis is considered upward.

When these conditions are met, the equation (8) takes the form:

$$grad\left(\frac{V^2}{2} + gz + \frac{p}{\rho} + \frac{V}{k}\varphi\right) = 0. \tag{9}$$

From the equation (9) it follows that there is an integral of motion, which is an analogue of the Bernoulli-Euler integral, that is.:

$$p + \rho gz + \rho\frac{V^2}{2} + \frac{\mu}{k}\varphi = C, \tag{10}$$

where C = const. If the potential of the filtration rate φ(xyz) is known, then the equation (10) will allow calculate the pressure distribution in the moving fluid.

The well-known Laplace equation for our conditions looks like this:

$$\operatorname{div}(drad\varphi) = \Delta\varphi = 0 \tag{11}$$

At low flow rates, the expression $\rho\frac{V^2}{2}$ from the equation (10) can be neglected. Then for the potential we get the expression:

$$\varphi = -\frac{kp}{\mu} + const. \tag{12}$$

Example. Suppose you want to find the distribution in the forward flow of fluid for gravel filter conditions.

The equation (11) looks like this: $\frac{d^2\varphi}{dx^2} = 0$, whence $\varphi = C_1x + C_2$.

The integral (10) takes the form

$$p + \rho gz + \rho\frac{V^2}{2} + \frac{\mu}{k}(C_1 + C_2.) = const., \tag{13}$$

where it follows from:

$$p = -\frac{\mu}{k}C_1x + const. \tag{14}$$

If the pressure values are known at x = 0, x = l, then for p we get the values of p_o and p_1. Then for speed we get expression:

$$V = \frac{k(p_0 - p_1)}{\mu l} \tag{15}$$

III. Findings

The formula (15) can be applied to the experimental determination of permeability k for gravel filters. Mathematical support of the processes of movement of liquids in a gravel filter is important for solving practical problems in oil and gas production. The authors proposed a variant of the technology of washing the sorted quartz sand into a horizontal well filter that can be useful for oil companies developing and operating deposits with unstable reservoirs.

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