PHYSICS AND MATHS

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MODELING OF THE RESERVOIR-PIPELINE SYSTEM TAKING INTO ACCOUNT THE LAYER DEFORMATION

Abstract. *A model of the process of unsteady motion of fluid in the coupled "deformable reservoir-pipeline" system is structured and connected equations are solved. An analytic expression admitting to determine the influence of pressure change law on the bottomhole, harnesses to it and deformation of the reservoir on the dynamics of pressure at the outlet of the main pipeline, was obtained. Numerical calculations were carried out for various values of the system's parameters.*
Keywords. *Laplace transform, deformation, differential equation.*

1. Introduction

Oil production process consists of three interconnected motion of fluid: in a stratum, in lifting pipes and in the main pipeline. Any change that happens in one of them, is reflected in other flows. This, in the initial period leads the violation of the steady state of wells. Further, after some time, the wells switch to a different steady state, but with a different return.

Determination of the influence of this transition process on the existing mode of wells is of important applied and scientific value. Therefore, when modeling the oil production process, it is necessary to consider the "reservoir-well" and main line as a single system. Furthermore, in addition other factors, deformation of the formation matrix also may have essential influence on the fluid flow hydrodynamics. In spite of significant number of hydrodynamic studies of oil production process the issue of hydrodynamics of flow in the coupled system of "reservoir-pipeline" was not given due attention. Therefore, simulation and study of hydrodynamics process in a "reservoir-pipeline" system allowing for deformation of the formation matrix is of scientific and practical significance.

2. Statement and solution of the problem

Let us consider the process of homogeneous fluid filtration in a uniform annular deformable reservoir. In the first approximation we accept that permeability of reservoir due to its deformation depending on the pressure change linearly [1].

$$k(P) = k_0 - \frac{k_0 - k_c}{P_k - P_c(0)}(P_k - P) \tag{2.1}$$

where k_0 and k_c are initial permeability on the contour and pore channel wall.

Within the accepted assumptions, the differential equation of flat-radial filtration of fluid will have the form

$$\frac{\partial \Delta P}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left[\chi(P) r \frac{\partial \Delta P}{\partial r}\right], \tag{2.2}$$

where

$$\Delta P = P - P_k, \quad \chi(P) = \frac{k(P)}{\mu\beta^*}. \tag{2.3}$$

The initial and boundary conditions

$$\Delta P\big|_{t=0} = \frac{P_k - P_c(0)}{ln\left(\frac{R_k}{r_c}\right)} ln\left(\frac{R_k}{r}\right), \quad r_c \le r \le R_k, \tag{2.4}$$

$$\Delta P\big|_{r=R_k} = 0, \quad t > 0, \tag{2.5}$$

$$\Delta P\big|_{r=r_c} = P_k - P_c(t), \quad t > 0. \tag{2.6}$$

3. Fluid flow in the tubing

Now we consider fluid flow in a tubing. Taking the fluid as dropping, compressible, homogeneous, for the equation of its flow in the pipe and continuity equation we have [2]

$$-\frac{\partial P}{\partial x} = \frac{\partial Q_1}{\partial t} + 2aQ_1,$$

$$-\frac{1}{c^2}\frac{\partial P}{\partial t} = \frac{\partial Q_1}{\partial x}, \tag{3.1}$$

where $c^2 = \frac{\partial P}{\partial \rho}$ *; c is the sound speed in fluid,* $Q_1 = \rho u$ *is the mass flow rate in the unit area of flow section of the pipe* ρ *is fluid density, u is fluid flow speed averaged along cross section of the pipe, a is a resistance factor.*

Differentiating both hand sides of the first equation with respect to *x*, the second equation with respect to *t* of the expression (3.1) and subtracting them term by term, we get:

$$\frac{\partial^2 P}{\partial t^2} = c^2 \frac{\partial^2 P}{\partial x^2} - 2a\frac{\partial P}{\partial t} \tag{3.2}$$

The initial and boundary conditions

$$P(x,0)\big|_{t=0} = P_c(0) - 2aQ_{10}x, \quad 0 \le x \le l, \tag{3.3}$$

$$\left.\frac{\partial P}{\partial t}\right|_{t=0} = 0, \quad 0 \le x \le l, \tag{3.4}$$

$$P\big|_{x=l} = P_y(t), \quad t > 0, \tag{3.5}$$

$$P\big|_{x=0} = P_c(t), \quad t > 0. \tag{3.6}$$

We shall look for the solution of the equation (3.2) allowing for conditions (3.5) and (3.6) in the form:

$$P = P_c(t) - \frac{P_c(t) - P_y(t)}{l}x + \sum_{i=1}^{n}\varphi_i(t)\sin\left(\frac{i\pi x}{l}\right) \tag{3.7}$$

Differentiating formula (3.7) with respect to *x* and then substituting to the first equation in (3.1), we get

$$\frac{P_c(t)}{l} - \frac{P_y(t)}{l} + \sum_{i=1}^{n}\varphi_i(t)\frac{\pi i}{l}\cos\left(\frac{i\pi x}{l}\right) = -\frac{\partial Q_1}{\partial t} - 2aQ_1 \tag{3.8}$$

Applying the Laplace transform, and then convolution and inversion theorems, from equation (3.8) we get

$$\overline{Q}_1 = \frac{Q_1(0)}{s+2a} + \frac{\overline{P}_c}{l(s+2a)} - \frac{\overline{P}_y}{l(s+2a)} - \sum_{i=1}^{n}\overline{\varphi}_i\frac{\pi i}{l(s+2a)}\cos\left(\frac{i\pi x}{l}\right) \tag{3.9}$$

4. Fluid flow in the main pipeline

We consider the fluid flow in the main pipeline. We locate the origin of the coordinate axis x_1 at the inlet of the pipeline and direct it in the direction of fluid flow. Assume that at some time moment oil line with flow rate G is connected to the main pipeline at the distance l_2 from the origin of the coordinate axis x.

Then fluid flow in the main pipeline will be of the form [3]

$$\frac{\partial^2 P}{\partial t^2} = c^2 \frac{\partial^2 P}{\partial x^2} - 2a_3 \frac{\partial P}{\partial t} - \frac{2a_3 c^2 G}{f_1} \delta(x_1 - l_2) \tag{4.1}$$

Initial and boundary conditions:

$$\left. \frac{\partial P}{\partial t} \right|_{t=0} = -c^2 \frac{G}{f_1} \delta(x_1 - l_2) \tag{4.2}$$

$$P(x,0)\big|_{t=0} = P_{yc}(0) - 2a_3 Q_{20} x_1 \tag{4.3}$$

$$P\big|_{x_1=0} = P_{yc}(t) \tag{4.4}$$

$$P\big|_{x_1=l_1} = P_{вых}(t) \tag{4.5}$$

Having solved problem (4.1) - (4.4), we determine P_{wh} the pressure dynamics at the wellhead pressure for any form of pressure change at the outlet of the transport pipeline and its connections, as well as the volume of the flowing fluid and the volume of fluid flowing through any pipe cross-section per unit time, taking into account the dynamic connection of the reservoir-well system. Numerical calculations are performed for various practical values of the system parameters (fig.1).

Conclusion. A model of unsteady fluid movement in the conjugate reservoir-pipeline system is built taking into account the deformation of the reservoir rock and connections to it. An analytical expression has been obtained that makes it possible to determine the pressure dynamics at the outlet of the main pipeline at a given law of pressure change at the bottom of the well and deformation of the formation rock skeleton, which is of great practical importance.

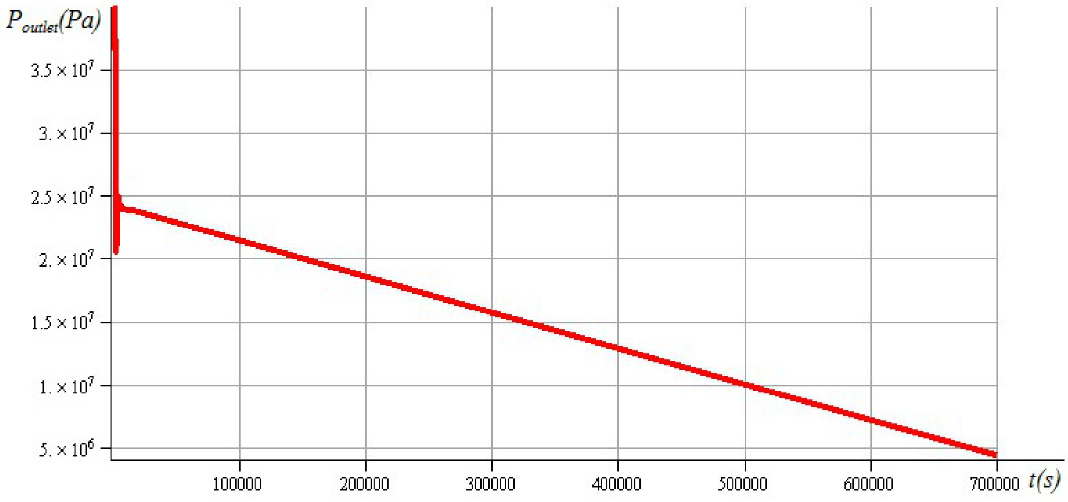

Fig. 1. **Dynamics of pressure change at the outlet of the pipe, for *t=700000 s***

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