CONFERENCE PROCEEDINGS

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Digital field

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Abstract. The paper presents the developed computational technologies that participate in a complex of programs for creating a digital model of an operating field. Linear methods of processing the areal systems of seismic observations, as well as algorithms for determining the electromagnetic parameters of the near wellbore space for a horizontally layered medium, are developed. A computational technology was developed that allows real-time monitoring of well production rate, gas factor and water cut for additional thermodynamic parameters of wells. On the basis of this technology, methods are implemented to maximize the production of the existing field, taking into account the diameter of the pipelines, the intensity of production, etc. The algorithms for determining the reservoir field filtration coefficient from the pressure data specified in the injection and production wells have been developed, on the basis of which the drilling of new additional injection and production wells has been optimized.

Keywords: inverse problems, computational methods, filtration, logging, seismic survey, high-performance computing

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Processing of seismic data of areal measurement systems

At present, thanks to areal observation systems, it was possible to create a fundamentally new method for solving three-dimensional inverse problems, in which the following is used: the three-dimensional analogue of the M.G. Krein equation (Kabanikhin, 1989; Kabanikhin et al., 2004; Kabanikhin, Shishlenin, 2011), parallel computing on high-performance clusters, Monte-Carlo methods (Kabanikhin et al., 2015b; Kabanikhin et al., 2015c), super fast processing algorithms for block-Toeplitz matrix of large dimensions (Kabanikhin et al., 2015a).

The main problem of studying three-dimensional elastic media is the large size of the region; even for a section of 2 km×2 km×2 km, the solution of the direct seismic survey problem with a resolution of 1 meter can take up to 150 hours on 80 cores of a single node of a computing cluster. And if we take into account that most modern methods for solving inverse problems are based on iterative procedures, then even the number of operations required to perform several iterations can lead to uncontrollable errors. This circumstance is complicated by the strong incorrectness of the inverse problems, which consists in the nonuniqueness of the solution, as well as in the instability, which greatly increases with depth.

Previously, an algorithm was proposed for the numerical solution of the inverse problem for systems of equations of the hyperbolic type (acoustics, Maxwell, Lamé equations) in three-dimensional space with additional information on a part of the half-plane (areal observation system) (Kabanikhin, Shishlenin, 2011). The basic idea is to apply the projection method with the subsequent reduction of the nonlinear inverse problem to a multiparametric family of linear integral equations (a multidimensional analog of M.G. Krein equation) (Kabanikhin, 1989).

Let us consider the inverse problem of determining velocity of the medium:

$$c^{-2}(x,y)u_{tt}^{(k)} = \Delta u^{(k)},\ x\in R,\ y\in R,\ t>0,\ k=0,\pm1,\pm2,\dots$$
$$u^{(k)}(x,y,0)=0;\ u_t^{(k)}(x,y,0)=e^{iky}\cdot\delta(x).$$

using additional information.

$$u^{(k)}(0,y,t)=f^{(k)}(y,t),\ u_x^{(k)}(0,y,t)=0,\ k=0,\pm1,\pm2,\dots$$

Let τ(x, y) be a solution to the Eicolnal equation:

$$\tau_x^2+\tau_y^2=\frac{1}{c^2(x,y)},\ x>0, y\in R;$$
$$\tau(0,y)=0,\ \tau_x(0,y)=\frac{1}{c(0,y)},\ y\in R.$$

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We introduce new variables and functions:

$$z = \tau(x,y), \quad y = y.$$
$$v^{(k)}(z,y,t) = u^{(k)}(x,y,t), \quad b(z,y) = c(x,y).$$

Then the nonlinear coefficient inverse problem can be reduced to a family of integral equations (a multidimensional analog of M.G. Krein equation):

$$\sum_m S^m(z,y) f_m^{k'}(t-z) + w^{(k)}(z,y,t) +$$
$$+\sum_m \int_{-z}^{z} f_m^{k'}(t-s) w^{(m)}(z,y,s)\,ds = 0,$$
$$|t| < z, \quad k = 0, \pm 1, \pm 2, \ldots$$

Here the function $w^{(m)}(z,y,t)$ has the following form:

$$w^{(m)}(z,y,t) = S^{(m)}(z,y)\delta(z-t) + Q^{(m)}(z,y)\theta(z-t) +$$
$$+ Q^{(m)}(z,y)\theta(z-t) + \widetilde{w}^{(m)}(z,y,t).$$

M.G. Krein equation should be supplemented with the following tasks:

$$\begin{cases} 2S_z^{(m)} + qS_y^{(m)} + pS^{(m)} = 0, & z > 0,\ y \in R, \\ S^{(m)}(0,y) = \frac{1}{2} e^{imy} \end{cases}$$

$$\begin{cases} 2Q_{zz}^{(m)} = S_{zz}^{(m)} - \left[qQ_y^{(m)} + b^2 S_{yy}^{(m)} + pQ^{(m)}\right], & z > 0,\ y \in R, \\ Q^{(m)}(0,y) = 0 \end{cases}$$

Here

$$q(z,y) = 2b^2(z,y)\tau_y,\ p(z,y) = b^2(z,y)(\tau_{xx} + \tau_{zz}),$$
$$b(z,y) = c(x,y).$$

Determination of parameters of existing wells using standard pressure and temperature sensors

Extraction of oil from wells is carried out either due to natural spouting under the action of reservoir pressure, or by using one of the mechanized methods of lifting liquid. usually in the initial stage of development, the fountain production is in operation, and as the flow-out weakens, the well is transferred to the mechanized method. One of the important tasks of diagnosing the state of a well is the operative determination of changes in well flow rate, gas factor and water cut (Kabanikhin et al., 2011). Earlier, an algorithm was developed for estimating these parameters, based on a numerical simulation of a direct problem consisting in determining the pressure and temperature along the wellhead of a vertical well from a given temperature and pressure at the bottom of the well. The methods for calculating the direct problem for the acting well are based on solving the heat and mass transfer equations. To calculate the thermophysical properties of the water-oil-gas mixture, data are used on the standard characteristics and composition of the oil-gas mixture, empirical correlations, diameter and slope of the well, flow patterns (bubble, cork, ring) and others. The distribution of pressure and temperature in the wellbore, taking into account the structure of the flow and the depth of degassing. Differential heat and mass transfer equations are solved numerically from the bottom to the wellhead. In the inverse problem, it is required to determine the flow rate, gas factor and water cut according to the pressure and temperature measured at the wellhead. The works (Ryazantsev et al., 2013; Kabanikhin et al., 2011) show developed algorithms for solving direct and inverse problems in the case where pressure and temperature measurements are made at a certain depth. In this paper, it is shown that this algorithm can be applied for the well to be used in the case when pressure and temperature are measured on the surface (in the wellhead) of the well. The importance of solving direct and inverse problems in a well is determined by the fact that at present only about 100 thousand wells are operated in Russia. Installation of special equipment that allows to carry out permanent well operation monitoring is complicated and expensive. Monitoring and computational technology were implemented using sensors included in the standard set of submersible pump telemetry and additional measurements of pressure and temperature on the surface in real time. Based on the developed algorithms, a computational technology has been implemented, which allows to maximize the production of the existing field taking into account the diameter of pipelines, the intensity of production, etc.

Determination of the reservoir filtration of the existing field by pressure sensors installed in wells

One of the important tasks of the existing field is to determine reservoir parameters by measuring the pressure inside the wells of the field. On the basis of a mathematical model of the diffusion equation, the inverse problem is solved to determine the filtration coefficient according to the pressure given in the injection and production wells. The problem is reduced to solving a multidimensional coefficient inverse problem for the diffusion equation using data measured in a discrete set of points (Kabanikhin, Shishlenin, 2018).

The problem of optimizing the placement of additional injection and production wells was also solved, taking into account the data obtained in solving the inverse problem.

Determination of electromagnetic parameters of the near-wellbore space

A computational technology has been developed that makes it possible to determine the electromagnetic parameters of the near-well space in the case of a horizontally layered medium in the case of one source and two receivers of the reflected signal. The formulas obtained at the interface between the media (on the basis of conservation laws) guarantee the physicality of the results obtained and the adequacy of solving the coefficient inverse problem (Romanov et al., 2010; Epov et al., 2011a; Epov et al., 2011b; Epov et al., 2011c).

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