Estimation of flow rate of oil loss as a result of damage of linear part of oil main

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Abstract
The process of oil leakage in case of seal failure of long operated underground oil pipeline is suggested. For diagnosing of leakages of oil and their liquidation the problem of regularities of oil filtering in the porous medium as a result of appearance of a source is solved. Oil filtering in the soil is described by the linear equations of Darci. The task is reduced to determination of influence of a point source on process of filtering by means of Dirac function. By means of mathematical transactions the equation allowing to predict change of pressure in the porous medium in time due to growth of the filtrational resistance caused by oil leakage from the pipeline is obtained. For determination of expense of a leakage it is suggested to use iterative method which assumes time splitting of leakage into discrete time periods Δt , during each of which leakage flow can be considered

as a constant. For the end of interval Δt the size of pressure of external resistance to the expiration is predicted and the leakage expense is determined.
The results obtained have practical value for forecasting of oil leakage expenses from the underground oil pipeline in time taking into account soil resistance.
Key words: OIL LEAKAGES, PRESSURE OF FILTRATIONAL RESISTANCE OF THE SOIL, LEAKAGE EXPENSE, FILTERING RATE

Existing system of oil and gas pipelines of Ukraine is in operation at average from 20 to 48 years, depending on the term of implementation of its components. During operation considerable part of the main oil and gas pipelines and processing equipment has depleted their reserves, repeatedly was subjected to routine and general maintenance and is already outmoded. Their further safe and reliable operation is possible only in case of periodic complex of works on structural scrutiny, establishment of working capacity, residual resource of safe operation, carrying out of cost effectiveness analysis and further upgrade [1, 2, 3].

Specified terms of operation of pipelines are considerable and at untimely and low-quality performance of planned maintenance of linear part there is an increase of risk of emergencies with depressurization of the pipeline and oil spills [2, 4].

Losses of transported medium on size of costs of leakage can be divided into small and large sources. Appearance of sources of the first sort does not influence on the parameters of operating mode of oil pipeline and cannot be fixed by dispatching service. Their origin can be fixed as a result of penetration of transported product on the Earth's surface [4]. Big leakages lead to change of parameters of oil pipeline mode and can be recorded by the dispatcher.

Often corrosion processes, which lead to formation of penetration defects in a pipeline wall, are the cause of origin of small leakages from the oil pipeline.Emergency leak is characterized by certain oil flow, which depends on pressure in oil pipeline in the leakage point and counter-pressure of external medium, which is defined by the filtrational resistance of the soil. Therefore an important task of diagnostics of leakages from the oil pipeline and technology of their liquidation is the task of regularities of oil filtering in the porous medium as a result of source appearing. Oil filtering in the soil is described by the linear equations of Darci

$$w = -\frac{k}{\eta}\frac{\partial p}{\partial x} \qquad (1)$$

where w – filtering rate; $\frac{\partial p}{\partial x}$ – barometric gradient; k – soil permeability; η – oil viscosity (absolute); c – sound speed in environment [5, 6].

The linear source which is created by leak of oil from the oil pipeline and is the reason of pollution of the soil, can be modelled by point source by means of Dirac's function. So, the task is reduced to definition of influence of point source on filtration process

The continuity equation in linear statement taking into account point source having specific intensity can be written down as follows:

$$-\frac{\partial \rho}{\partial t} = \frac{\partial(\rho w)}{\partial x} - q\,\delta\left(x - x_q\right), \qquad (2)$$

where $\delta\left(x - x_q\right)$ – Dirac function, x_q – source coordinate [6, 7].

In case of point source with intensity q (kg/s) with coordinates $\left(x_0,\ y_0\right)$ the equation looks as follows

$$\frac{\partial P}{\partial t} = æ\left(\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2}\right) - æ\frac{qa}{F}\delta\left(x - x_0\right)\delta\left(y - y_0\right), \qquad (3)$$

where $\delta\left(x - x_0\right)$, $\delta\left(y - y_0\right)$ – function of Dirac source; P – pressure in porous medium; x, y – space coordinates; t – time;

$$æ = \frac{c^2}{a},\quad a = \frac{\nu}{k};$$

ν – kinetic oil viscosity; F – orifice area, through wichthe oil leakage takes place.

Let us consider that till the beginning of source action (t=0), the system rests and excess pressure in all points of the area was equal to zero, i.e. $P(x, y, 0) = 0$

Let us excess pressure on the surface of the soil during source action remains unchanged, i.e. at $t > 0$ we will have $P(x, 0, t) = 0$.

Then this boundary problem is reduced to such one for half-space

$$\frac{\partial P}{\partial t} = æ\left(\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2}\right) - æ\frac{qa}{F}\delta(x - x_0)\delta(y - y_0), \quad (4)$$

$$P(x,0,t) = 0; \quad P(x,y,0) = 0. \quad (5)$$

For solution of the task (4) in the conditions of (5) we will use Fourier sine transformation along the variable y and Laplace transformation in time t

$$\frac{d^2\overline{W}}{dx^2} - \left(\frac{S + æ\lambda^2}{æ}\right)\overline{W} = \frac{qa}{FS}\sin\lambda\, y_0\ \delta(x - x_0). \quad (6)$$

Heterogeneous equation (6) we will solve by the method of variation of certain variables.

$$\overline{W} = \frac{q\sin\lambda\, y_0}{2FS\alpha}e^{\alpha(x-x_0)}\sigma(x - x_0) + B_1 e^{\alpha x} - \frac{q\sin\lambda\, y_0}{2FS\alpha}e^{-\alpha(x-x_0)}\sigma(x - x_0) + B_2 e^{-\alpha x}. \quad (7)$$

Since from the physical essence the tasks

$$\lim_{x\to\infty} w = 0 \text{ and } \lim_{x\to-\infty} w = 0,$$

then the equations are true

$$\lim_{x\to\infty}\overline{W} = 0, \ \lim_{x\to-\infty}\overline{W} = 0.$$

Considering this we will obtain

$$B_1 = -\frac{q\sin\lambda\, y_0}{2FS\alpha}e^{-\alpha x_0}, \quad B_2 = 0. \quad (8)$$

Through mathematical transformations we will obtain

$$P(x,y,t) = \frac{æqa}{2\pi F}\int_0^\infty \frac{\sin\lambda\, y_0 \sin\lambda\, y}{\lambda}\left\{\left[\sigma(x - x_0) - 1\right]\left[e^{-\lambda(x_0-x)}erfc\left(\frac{x_0 - x}{2\sqrt{æt}} - \lambda\sqrt{æt}\right) - e^{\lambda(x_0-x)}erfc\left(\frac{x_0 - x}{2\sqrt{æt}} + \lambda\sqrt{æt}\right)\right] - \sigma(x - x_0)\left[e^{-\lambda(x-x_0)}erfc\left(\frac{x - x_0}{2\sqrt{æt}} - \lambda\sqrt{æt}\right) - e^{\lambda(x-x_0)}erfc\left(\frac{x - x_0}{2\sqrt{æt}} + \lambda\sqrt{æt}\right)\right]\right\}d\lambda. \quad (9)$$

Obtained equation allows to predict change of pressure in the porous medium in time due to growth of filtrational resistance caused by oil leakage from the pipeline. When $x - x_0$ and $y = y_0$ the equation (9) allows to determine pressure level, which prevents leakage. However, in analytical form it is impossible to describe process of oil leakage from the pipeline, as in (9) it is considered that oil leakage value from the pipeline is a constant. In case of change of pressure of external resistance the leakage value will also change in time, which is not considered in (9). Therefore for the solution of a task it is suggested to use iterative method, which assumes time splitting of the leakage into discrete intervals Δt, during each of which the expense of leakage can be considered as a constant. For the first time span pressure of counteraction to the leakage should be considered as equal to hydrostatic pressure of soil on pipeline depth. Then volume flow of leakage will be as follows:

$$Q = F\mu\sqrt{2\left(\frac{P_T - P_3}{\rho}\right)}, \quad (10)$$

where P_T, P_3 – pressure in the pipeline and pressure of external resistance respectively; ρ – density; F – orifice area; μ – leakage factor.

According to (9) it is possible to predict the value of pressure of external resistance to the leakage $P_3 = P(x_0, y_0, \Delta t)$ at the end of interval Δt and new leakage flow according to (10) is determined. Thus, the smooth curve of change of leakage flow rate in time is replaced with step dependence, which in case of the choice of rather small interval of iterations Δt can adequately reflect the real nature of leakage.

The figure shows dependences of change of pressure of filtrational resistance of medium (pressure of counteraction to the leakage) and changes of leakage flow in time constructed for various characteristics of soil.

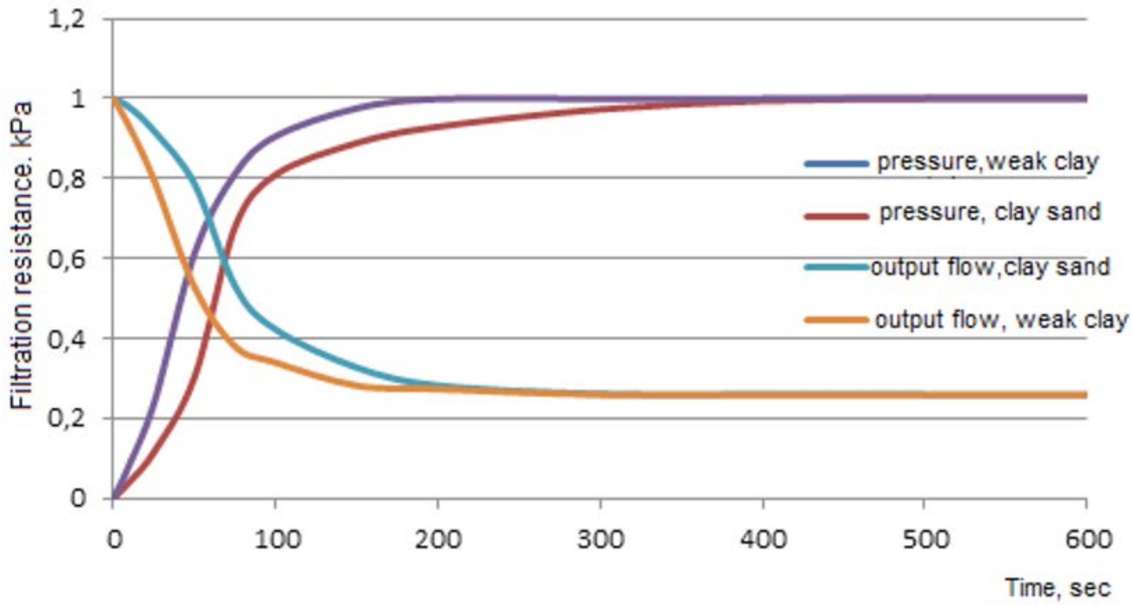

Figure. Dependence of pressure and expense of flow on time for various soils

Analysis of obtained characteristic curves shows that the increase of pressure of counterforce to the leackage due to soil filtration resistance is determined by permeability of the porous medium and physical-oil properties. During steady pressure in the oil pipeline and permanent cross section of leakage, the increase of filtration resistamce pressure leads to decrease of leakage flow.

Duration of non-stationary oil filtration in the soil depends on the permeability of porous medium and can fluctuate in vast time span. Increase of soil permeability leads to growth of non-stationary filtration. So, for soils of clay sand type, time of non-stationary filtration makes about 400 s, and for soils of weak clay type it makes 150 s.

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