MODELING OF OIL OUTPUT INTENSIFICATION DUE TO HEATING PROCESS AT ACOUSTICAL STIMULATION IN A WELL.

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ABSTRACT

The problem about possible physical mechanisms resulting in oil output intensification from a well at acoustical stimulation is considered.
The advanced model of physical processes taking place at acoustical stimulation is considered in the framework of the heating mechanism. The porous fluid is considered as consisted of light and heavy hydrocarbonaceous phases, which are in a thermodynamic equilibrium. Filtration or acoustical stimulation can change equilibrium balance between phases so the heavy phase can be precipitated on pores walls or dissolved. The given model allows to reproduce the basic features of fluid filtration in a well during and after acoustical stimulation.

Introduction

The long-years practice of works with acoustic wave sounding (AWS) technology has demonstrated the economic feasibility in various mining-geological conditions with a wide range of collector properties. There are numbers of articles devoted to an explanation of physical phenomena having place at AWS [1-4]. Accordingly to many of them, the physicochemical mechanisms of fluid viscosity drop under ultrasound action are considered as the basic processes taking place at AWS operations [1]. The oil in the reservoir conditions is a multiphase composited medium. Due to its inhomogeneity the reservoir fluid gets with time a structural viscosity, which significantly exceeds the initial one that, in turn, leads to decreasing of oil output. The intensive vibration processes at ultrasonic action are capable to destroy these interfractional formations and by that to increase the oil output. Thus, it is possible to speak about thixotropic changes occurred at AWS. Cavitations processes, appeared at ultrasound action, also have probably an effect on improving of filtration characteristics of oil [4]. However, the mathematical description of these processes and their quantitative analysis is also enough complicated problem in conditions of a porous space.

In the report the thermal mechanism of oil viscosity decreasing at AWS is considered. The given problem is a complex, composited one and it combines as calculations of the ultrasonic field as well as mechanism of its action and the following fluid filtration through a porous medium.

Sequence of phenomena

Let in a well there is a source of ultrasonic oscillations, which radiates ultrasonic waves into surrounding medium. Then the ultrasonic field will exist in the borehole vicinity, which is characterized by energy density in each point of medium. In the presence of dissipation in medium, a part of mechanical energy of ultrasonic waves will dissipate, converting into the thermal energy. By virtue of it there are the thermal sources distributed with some density in the borehole vicinity, which heats the surrounding medium. As the viscosity of oil exponentially depends on temperature, its changing can have an effect for a regime of oil filtration from a reservoir, leading to increasing of filtration rate in the borehole vicinity, and, probably, to effective washing of filtration zone with removing of absorbed and of coagulated particles, preventing the oil filtration into a well.

Acoustical field

Let's consider the fluid-filled well of radius R with a monochromatic ultrasonic emitter on its axis, which represents a couple of monopole acoustic sources placed on the distance Z one from another. The power of the source I let to be 1 kWt. The borehole fluid is characterized by density ρ_f and sound velocity c_f. The surrounding elastic medium is characterized by density ρ and velocities of longitudinal c_l and transversal c_s waves.

To find the ultrasonic field in the borehole vicinity, the problem on determination of the displacement potentials of longitudinal wave in a borehole fluid φ_f ($\vec{U}_f = grad\,\varphi_f$) together with both the scalar φ and vector $\vec{\psi}$ displacement potentials for elastic medium ($\vec{U} = grad\,\varphi + rot\vec{\psi}$) is solved. The final solution of the problem can be written in the form of Fourier integrals by wave number k [5]:

$$\varphi(r,z,\omega) = \frac{1}{2\cdot\pi}\cdot\int_{-\infty}^{\infty} e^{-i\cdot k\cdot z}\cdot\cos(\Delta z\cdot\kappa)\cdot\varphi(r,\kappa,\omega)dk \qquad (1)$$

$$\psi(r,z,\omega) = \frac{1}{2\cdot\pi}\cdot\int_{-\infty}^{\infty} e^{-i\cdot k\cdot z}\cdot\cos(\Delta z\cdot\kappa)\cdot\psi(r,\kappa,\omega)dk \qquad (2)$$

where $\varphi(r,k,\omega)$ and $\psi(r,k,\omega)$ spatial Fourier components.

Using the determined displacements field, it is possible to find the power of the thermal sources, which arising due to dissipation of energy, radiated by the high-frequency ultrasonic emitter.

Acoustical energy density

The mean power of dissipated ultrasonic energy, averaged by a period, is expressed through the mean energy density by the relations:

$$\dot{\bar{E}}_l = \gamma_l\cdot\bar{E}_l \qquad \dot{\bar{E}}_s = \gamma_s\cdot\bar{E}_s, \qquad (3)$$

where $\gamma_l = \alpha_l\cdot c_l$, $\gamma_s = \alpha_s\cdot c_s$ are absorption constants for longitudinal and transversal waves, and α_l and α_s – are the decay factors with distance for the same waves. Due to the fact that in any system making small oscillations, the mean by period value of total potential energy is equal to the mean value of total kinetic energy, it is possible to write:

$$\bar{E}_l = \rho\cdot\overline{V_l^2} \qquad \bar{E}_s = \rho\cdot\overline{V_s^2} \qquad (4)$$

where V_l and V_s are mass velocities of longitudinal and transversal waves.

In its turn, the power of thermal sources density $Q_T(r,z)$ is determined from relation $\rho\cdot C_P\cdot Q_T(r,z) = \dot{\bar{E}}_{\text{ìðõ}}$, where C_p – heat capacity. It leads to the following expression

$$Q_T(r,z) = \frac{1}{\rho\cdot C_p}\cdot\left[\gamma_p\cdot E_p + \gamma_s\cdot E_s\right] = \frac{1}{C_p}\cdot\left[\gamma_p\cdot\left(\left|V_r^{\varphi}\right|^2 + \left|V_z^{\varphi}\right|^2\right) + \gamma_s\left(\left|V_r^{\psi}\right|^2 + \left|V_z^{\psi}\right|^2\right)\right] \qquad (5)$$

The density distribution of thermal sources calculated by the mentioned above formulas, is shown in fig.1 in logarithmic scales of amplitudes.

Thermal field

To calculate the changes of thermal field in the borehole vicinity under action of distributed thermal sources, the mathematical statement of the problem is formulated in the cylindrical coordinate system. Then the heat conductivity equation will look as follows:

$$\frac{\partial T(r,z,t)}{\partial t}=\frac{1}{C_p(r)\cdot\rho(r)}\cdot\left[\frac{1}{r}\cdot\frac{\partial}{\partial r}\kappa(r)\cdot r\frac{\partial}{\partial r}T(r,z,t)+\kappa(r)\cdot\frac{\partial^2 T(r,z,t)}{\partial z^2}\right]+Q_T(r,z)\cdot\left[\Theta(t)-\Theta(t-T_{è})\right] \quad (6)$$

where $\Theta(t)$ – is unit function, $T_{è}$ – is the duration of a source operation.

Because of small attenuation in a borehole fluid the power density of thermal sources inside of borehole can be considered as equaled to zero.

The dynamics of a thermal field is estimated by the finite-difference procedure. To solve two-dimensional heat conductivity equation, the implicit split method is used.

The distribution of the thermal field in the moment T, corresponding to 24 hours of continuous action of ultrasound emitter, is shown in fig. 2.

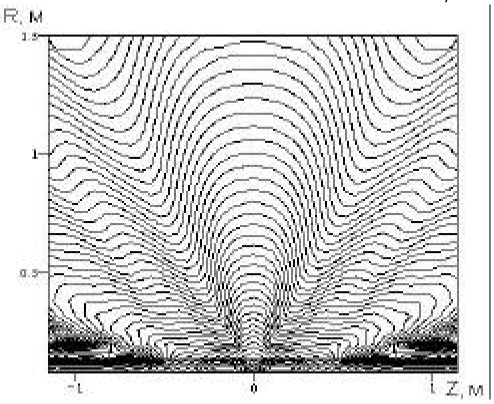

Fig. 1.

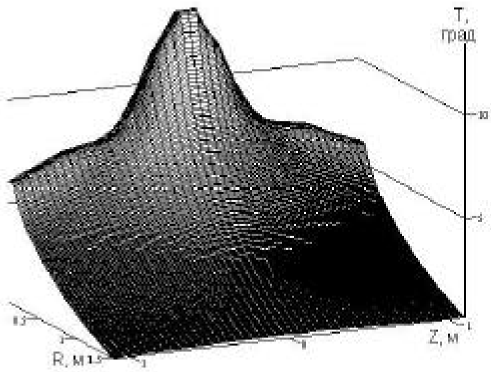

Fig. 2.

At long-time action (more than 18 hours) the temperature in the borehole vicinity increases on 10-14 C^0 degrees that corresponds to the data of thermometry [3].

Pressure field

Having determined the values of thermal field in each point of space, the change of oil viscosity is possible to calculate for whole region of consideration. The obtained data show, that at the temperature inside well 30 C^0, the additional heating on 10 C^0 results in change of fluid viscosity from 1,4 up to 1,1 mPa·sec., i. e. approximately on 27 %, that leads to certain increasing of oil output.

The oil filtration in porous medium is described by the filtration equation, obtained with use of linearized continuity equation, the Darcy's law and the state equation:

$$\frac{\partial P}{\partial t}-\rho_f\cdot c_f^2\cdot div\frac{k_0}{\eta\cdot m}\cdot grad\,P=0\,. \quad (7)$$

As it was already mentioned above, the fluid viscosity in this equation is a function of temperature, and consequently, a function of both coordinates and time $\eta=\eta(T(\vec{r},t))=\eta(\vec{r},t)$. By the form the filtration equation (7) is similar to homogeneous equation of thermal conductivity (6), therefore for its solution it is possible to use the same scheme, which was used for calculation of a thermal field. The calculations demonstrate, that the pressures field forms the depression whirlpool in the borehole vicinity. The characteristic time of achievement of steady state regime is approximately τ_f=2 sec, that is essentially less then relaxation time of temperature field at chosen parameters.

Estimation of oil output.

The total fluid output is determined as integral by surface of the perforated interval of the well from the mass fluid flow $\rho_f\cdot\vec{V}$ during the time t and it is expressed by the formula

$$Q=2\pi R\,\rho\int_0^t dt'\int_0^h dz\;V(R,z,t')\;. \quad (8)$$

The curves shown in fig.3 by solid lines correspond to the oil output after fulfillment of operations on AWS technology, while the dotted ones corresponds to the same case without AWS. Each of the three numbered groups of curves corresponds to various values of permeability coefficient (for 1 group the value of permeability coefficient is 240 mD, for 2 group - 120 mD, for 3 group – 60 mD).

The quantitative estimation has shown, that the effect of output increasing due to the oil viscosity drop at medium heating by the ultrasonic emitter, can be observed during 5-6 day after ultrasonic action. The quantity of additionally produced oil, being the difference between the quantity of oil extracted at AWS and without one, is shown in fig.4.

As it seems from fig. 4, while cooling the quantity of additionally produced oil achieves a constant level approximately in 5-6 day, that speaks about disappearance of positive effect at AWS, dealt with the only thermal heating, considered in the report. The curves showed in fig.4, are obtained for reservoirs with different permeability coefficients 240, 120 and 60 mD. Thus, the volumes of additionally produced oil at single-time single-point AWS with duration of 24 hours are, respectively, 0,1 tons for a permeability 60 mD and 0,36 tons for a permeability 240 mD. That does not exceed 5 % from the total volume of produced oil, and, thus, is not essential.

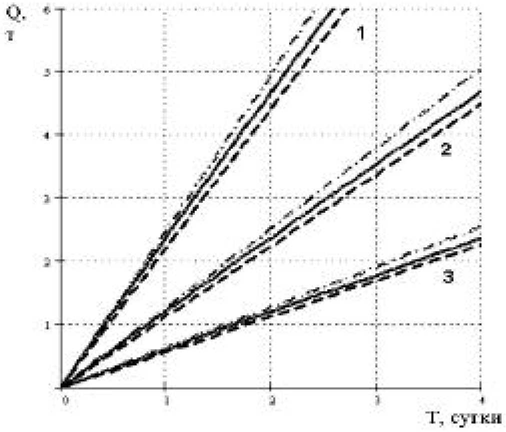

Fig. 3.

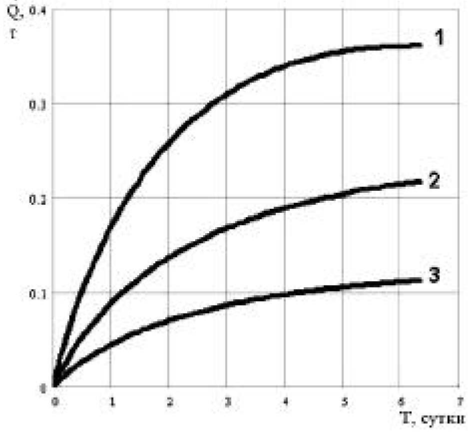

Fig. 4.

Thus, the basic stages, dealt with modeling of heating and oil filtration at ultrasonic action (AWS) are considered in the report. For this purpose the set of related problems, dealt with physical phenomena occurred at ultrasonic action due to the thermal mechanism, was formulated and solved.

Conclusion

The obtained estimations of AWS efficiency due to the thermal mechanism demonstrate the presence only its short-time (within several days after AWS application) effect. At the same time experimental data [3] show enough long-time (up to several months) effect of AWS.

It is necessary, however, to take into account, that together with a simple heating of a fluid in the borehole vicinity as the melting of heavy hydrocarbons, subsiding in pores, is occurred as well as the thixotropic changes of fluid properties. The weak intermolecular connections are destroyed, and there is an effective outwashing of structured blocks of oil. Thus, as well as the direct shaking of porous fluid, its heating can also result in long-time effects if to take into account the destruction, melting and subsequent outwashing of its structured blocks at heating. The mathematical model, describing the mentioned effects, is developed and presently it is under the testing.

The filtration model of stratum fluid consisted of light and heavy components is suggested in the report. This model describes the long0time character of acoustical stimulation, observed experimentally. It is well known that stratum fluid consists of different components: oil, water, gas, asphaltenes etc. Its filtration accompanies by slow separation, coagulation and sedimentation of heavy hydrocarbons on the pore space wells. That leads to gradually decreasing of pores diameter and hence to decrease of porosity and permeability. The characteristic times of these processes can be of order of several months and years. Under the acoustic action the process of coagulation and sedimentation of heavy fraction can be reversed with increase of temperature and pressure. It leads to melting of condensed fraction and its outwash from porous space. This behavior of two component fluid model explains the long-time positive effect of acoustical heating, because fast melting and cleaning of porous space changes by long-months slow processes of coagulation and sedimentation of heavy hydrocarbons and decreasing of porous channels.

The mathematical description of supposed model can be expressed in terms of filtration equation for pressure of porous fluid, diffusion equation for addition concentration and equation pore radius dynamics:

$$
\begin{aligned}
& m \cdot \frac{\partial P}{\partial t} - \boldsymbol{r}_f \cdot div\left(\frac{k}{\boldsymbol{h}} \cdot grad\ P \right) = 0\,, \\
& \frac{\partial \tilde{N}}{\partial t} + \vec{U} \cdot \nabla C + D \Delta C = -\frac{\left(C - C_*\right)}{\boldsymbol{t}} \\
& \frac{\partial r}{\partial t} = -r \cdot \frac{\boldsymbol{r}_f}{\boldsymbol{r}_s} \cdot \frac{m_a}{m_b} \frac{\left(\tilde{N} - \tilde{N}_*\right)}{\boldsymbol{t}}\,,
\end{aligned}
\qquad (9)
$$

where $\boldsymbol{r}_f$ and $\boldsymbol{r}_s$ are stratum fluid and solid sediment densities, C and C_* are current and equilibrium addition concentrations.

The obtained in the report numerical results show that in the framework of the suggested model it is possible to explain the long-time effect of acoustical stimulation observed experimentally.

REFERENCES

1. Gorbachev Y. I. Physicochemical bases of ultrasonic clearing of near bottom region of oil-wells // "Geoinformatika", 1998, ¹ 3, 1998, p. 7-12. (in Russian)
2. Gorbachev Y. I., Kuznetsov O. L., Rafikov R. S., Pechkov A. A. The physical principles of the ultrasonic method of action on collectors // "Geofizika", 1998, ¹ 4. (in Russian)
3. Pechkov A. A., Shubin A. V. Results of operations on increasing of wells efficiency by the method of ultrasonic action // " Geoinformatika ", 1998, ¹ 3, p. 16-24. (in Russian)
4. Kuznetsov O. L., Efimova S. F. Applying of ultrasound in oil industry. Moscow: Nedra, 1983, 192 p. (in Russian)
5. Petrashen. G. I., Molotkov L. A., Krauklis L. V. Waves in layered homogeneous isotropic media. V. 2. Leningrad: 1982. (in Russian)