Modeling of Oil Output Intensification Due to Heating Process in Porous Permeability Medium 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. There are many publications [1,2] with consideration of different mechanisms of oil viscosity decreasing under ultrasound action. However in practice the role of these mechanisms is appeared non-directly in the form of additional oil output. Thus the check validity of any physical model has to be carried out as with account of mechanism of acoustic action by itself as well with account of consequent stages dealt with fluid filtration into a well.

Taking into account only heating mechanism of acoustical action the set of acoustical, heat and filtration tasks was solved numerically, which shows that in the framework of single-component fluid model it is impossible to explain the longtime (several months) character of acoustical action [3]. 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 us to reproduce the basic features of fluid filtration in a well during and after acoustical stimulation.

INTRODUCTION

In spite of existence of apparent requirement of field geophysics in power physical methods directional on intensification of reservoir recovery at exploitation of wells, perhaps, any of existing methods of a raise of production performance is not learnt to the full. A successfulness of applying acoustical stimulation (AS) depends on a set of the factors, among which it is possible to dedicate filtrating-capacity properties of a medium, viscosity of a porous fluid, initial and flowing value of formation pressure, history variation of flow rate. However even a great amount of the accumulated statistical information about application of the AS method and experience of the specialists can not guarantee positive result of ultrasonic treating, don't speaking even about a quantitative estimation of possible effect of AS. By this reason the development of quantitative mathematical model describing the physical phenomena in porous permeable medium accompanied the AS is an actual problem.

There are a lot of different models describing certain physical processes at AS [1,2]. But due to complexity of the problem only the complete numerical simulation of oil filtration together with processes accompanied the AS could give the answer on the principal question: which of these models is more close to reality?

In the report the advanced model of physical processes at AS is represented in the framework of simple heating mechanism. The porous fluid, it is supposed, is composed from light and heavy hydrocarbonaceous phases, which are in a thermodynamic equilibrium. The external affects, such as a filtration or AS, can vary the balance between fractions so, that the heavy fraction can be absorbed on pores walls or be desolved. In the framework of the given model it is possible to reproduce the principal features of oil filtration behavior (oil output rate) from a well before and after AS.

THE PHYSICAL MODEL OF THE PHENOMENA

The stratum fluid is extremely non uniform medium composed of oils, water, gas etc. Its filtration is accompanied by slowly precipitation of heavy hydrocarbons on pore walls as a solid matter, that results in gradual decrease of a pore diameter, drop of permeability and porosity. The developed model of porous fluid consists of light and heavy fractions of hydrocarbons. The heavy fracture is considered as an admixture. In the steady state conditions both phases are in a certain balance which described by equilibrium concentration C_* of heavy phase, which is a function of basic thermodynamic parameters such as pressure and temperature. Obviously, that due to any external affect such as variation in filtration process accompanied by change of pressure or due to change of temperature at AS, the equilibrium concentration will change also. By this reason a thermodynamic state becomes to be non equilibrium one and precipitation or dissolution processes of heavy fraction begin to develop. It results to change of pores diameter and hence to variation of local porosity and permeability. The variation of these parameters, in its turn, leads to change in filtration and hence to changes in distributions of pressure and velocity fields. It again leads to a shift of local thermodynamic balance etc.

Thus the process of oil output decreasing during exploitation of oil well can be described in terms of step-by-step decreasing of oil rate yield due to penetrability and porosity drop, specially in the near well zone. The velocity of the given process can vary in a very wide domain, that depends as on physicochemical properties of resolvent and admixture, as well as on a stage of well development.

In turn, the ultrasonic waves, generated by an ultrasonic well emitter at AS, are absorbed in surrounding medium and form a distributed thermal source in neighborhood of a well. The increasing of local temperature leads to dissolution of heavy fracture and clearing of porous channels. Thus, a quick, practically instantaneous clearing of pores, especially in comparison with previous process, can explain a long-term effect of AS in the frameworks of simple heating mechanism.

Thus, in complete statement the simulation of oil output behavior at AS has to take into account the following aspects of the problem dealt with behavior of fluid in porous permeable medium without and with AS:

- fluid filtration with calculation of fluid flow through the perforated interval of a well;
- variations of local concentration of admixture;
- estimation of precipitation or dissolution rates, and corresponding changes of pore radius, porosity and permeability;
- propagation of ultrasound waves from well emitter with corresponding calculation of sound energy density distribution around a well and estimation of heat sources distribution;
- variations of temperature field around a well at AS.

All mentioned above processes are characterized by their own specific times. For example, if L is characteristic size of the problem (well diameter), then the time of sound wave propagation is $\tau_s = L/c$, where c is sound velocity; the heating time is $\tau_h = L^2/\chi$, where χ is a termo-conductivity coefficient; the filtration time has the order $\tau_f = (L^2 \eta m)/(\rho c^2 k)$, where ρ and η are density and viscosity of a fluid, k and m are permeability and porosity of a medium; the diffusion time of admixture is $\tau_D = L^2/D$, where D is diffusion coefficient; the transport time of admixture is $\tau_t = (L^2 \eta)/(k\,\Delta P)$, where ΔP is a depression jump; the time of precipitation or dissolution τ_C, which depends on temperature. The estimations of these specific times show that there is the following order in time scale of the mentioned physical processes $\tau_s << \tau_f << \tau_t \sim \tau_D \sim \tau_h << \tau_c$. This time scale allows us to split the complex problem on a set of quasi-independent subtasks, which are related only through their coefficients.

Diffusion and Transport of Heavy Admixture

There are three basic mechanisms for variation of heavy fracture concentration. They are the transport with resolvent flow, the diffusion and the absorption or dissolution on the pore walls. Thus, the governing transport equation for concentration of admixture can be written in the form

$$\frac{\partial C}{\partial t} + \vec{u} \cdot \nabla C + D \Delta C = -\frac{1}{\tau_c} \cdot \left(C - C_*(P,T)\right), \qquad (1)$$

where u - transport velocity of a resolvent fluid, and D - diffusion coefficient. The dynamics of a concentration field was estimated by the finite-difference procedure

Fluid Filtration and Oil Output Rate

The oil filtration in porous medium is described by the filtration equation for a pressure, obtained by linearization of continuity equation, the Darcy's law and the state equation of fluid. The dynamics of a pressure field was estimated by the finite-difference procedure by analogy with temperature and concentration fields. The calculated output rate is shown on the Fig.1 for comparison of two cases without and with AS. It is possible to see that at chosen parameters the duration of positive effect of AS is of order of 3 months, while the well degradation time has order of one year. The comparison of oil output rate at AS for two values of permeability 150 and 300 mD is shown on the Fig.2.

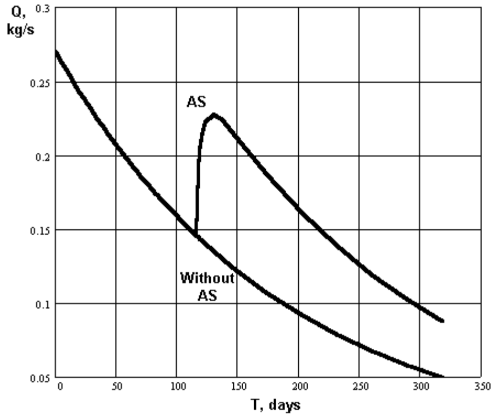

FIGURE 1. Variation of oil output rate in a well in dependence on time with and without AS.

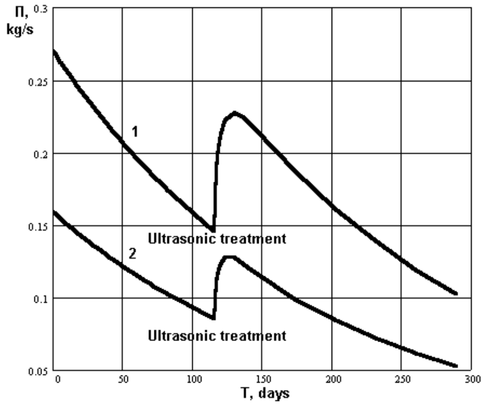

FIGURE 2. Variation of oil output rate in a well in dependence on time for two different values of permeability 300 and 150 mD (from the top).

CONCLUSION

The represented in the report numerical results of oil output rates show that the developed mathematical model of physical phenomena at AS is quite consistent and allows to reproduce the experimentally observed basic features of fluid filtration in a well before, during and after acoustical stimulation in the framework of simple heating model. Other physical mechanisms can be introduced into the developed model to understand which of them is adequate one.

REFERENCES

1. Kuznetsov O. L., Efimova S. F. Applcation of ultrasound in oil industry. Moscow: Nedra, 1983, 192p. (in Russian)
2. Gorbachev Y. I. Physicochemical bases of ultrasonic clearing in near bottom region of oil-wells // "Geoinformatika", 1998, № 3, 1998, p. 7-12. (in Russian)
3. Maksimov G. A., Radchenko A. V. Role of heating at ultrasonic affecting // "Geofizika", 2001, № 6. (in Russian)