053 VIBROSEISMIC STIMULATION FOR REHABILITATION OF HIGHLY WATERED RESERVOIRS

G.P. LOPUKHOV

All-Russian Scientific Research Oil and Gas Institute after Krylov,
c/o 10 Dmitrovsky Proezd, 125422 Moscow, Russia

Abstract

Correlation between oil rates and earthquakes was observed in the 1970s. It resulted in first attempts to use the energy of seismic waves to mobilize residual oil spreaded in the reservoir in the form of drops of different sizes, and to rehabilitate depleted oil fields with high water production.

Lab tests showed that oil displacement can be increased by application of low-frequency vibration. It was also confirmed by field tests (results reported at VI EOR ES, 1991): oil production due to vibroseismic stimulation increased by 30-40%.

However, estimations show that such increase of oil production can not be provided by low-frequency vibration. Most probably some unknown phenomena which impact on mechanizm of seismic vibration, resulted in oil production increase, are existed.

The object of this study is development of the mathematical model of vibroseismic stimulation on the basis of which mechanizm of residual oil mobilization can be explained. Such model can provide for effective action of vibration stimulation. This model oil saturated formation consists of blocks of different sizes. Each block with the big size includes several blocks with smaller sizes. Block sizes depend on geological processes taken place during their formationg, while correlation between their sizes does not depend on properties of materials of formed formation.

Core measurements taken in millimeter range and analysis of layer distribution during scunning in open hole taken in metric range shows that correlation between the big block sizes and small ones was in a rather small range and changes between 2.91 and 3.43.

Simulation of vibroseismic impact on formation shows that the process of low-frequency energy transfer from big blocks to small size blocks, producing high-frequency vibration, is taken place. These high-frequency vibrations provide for conditions when capillary forces, retaining oil drops in the porous media, are destroyed and conditions for oil mobilizations are appeared. These results are agreed with experimental data of noise measurements that was recorded during pilot commercial tests of vibroseismic action at different oil field in Russia. Thus the possibility of residual oil mobilization by aplying low-frequency vibroseismic stimulation was confirmed theoretically and in lab/field tests. Results received were essential part of creation of technology vibroseismic stimulation of waterflooded, depleted oil reservoirs.

1. Rehabilitation of highly watered reservoirs and vibrations.

The way of search for new efficient techniques of re-development of oil fields follows from natural process of gravitational segregation of oil and water in water-flooded reservoirs. On one side existing oil deposits were created in geological traps as a results of continuous gravitational migration of oil and water. After the development of oil field is over, residual oil will tend to accumulate again in the same traps, creating secondary oil deposits. On the other side the existance of multiple (over 30 thousand) concentrated oil accumulations (oil fields) all over the world has no unambiguous scientific explanation because of the existance of forces preventing from the manifestation of gravitation.

Nowadays the problem of secondary oil migration, directly determining the formation of oil deposits, is being solved with regard to a complex of energy phenomena in the entrails of the earth. Nature mechanisms wich may induce these phenomena are earthquakes, crustal deformation, being the result of moon and sun tides, various manifestations of geomagnetism, etc. Natural accumulation shows at least in principle the possibility of development of such techniques of reservoir stimulation which may accelerate this process. The use of such techniques can make possible repeated development of oil field after comparatively short period of time.

H.C. van Pullen suggests that up to now the development of oil reservoirs has had a form of overcoming natural capillary forces. According to his opinion we should prefer to use these forces instead of overcoming them and we have to try "to use natural tendencies to gravitation, capillarity, discontinuity of oil phase in order to accumulate fluid in the parts of reservoir having higher permability thus facilitating oil recovery, but not to overcome these forces"[1]. Most comprehensive description of the influence of vibrostimulation on rock is given in works of many authors in connection with the earthquakes. These effects include the change of water level in wells, disappearance and emergence of new mineral springs etc.[2]. The results of study of earthquake influence on mineral spring behaviour show that even weak earthquake changes mineral spring flow, temperature and mineral content. Such correlation is also observed for remote eartquakes [3,4]. Direct influence of earthquakes on oil production level is registered. The Starogroznskoje earthquake in January 7, 1938 (distance from epicentre is 30 km, magnitude - 4.8, seismic effect - 6 points) caused oil production increase by 45% and following production return to usual rate. There was confirmed known regularity of decrease of oil production before earthquake and increase and normalization of this value after earthquake [5]. After one of the strong earthquakes in Mountly -View in California oil production increased by 100% and maintained this level for a long period of time [6].

2. Vibration against capillary forces

Lab previous studies of gravity segregation have shown to influence on residual oil drops low-frequency vibration. It was to note that the mobility of oil drops depends on value of vibroacceleration when it approaches towards constant of gravity [7,8].

In waterflooded procceses the wave pressure gradient which is equal to external filtration pressure gradient. The critical parameter has a following form

$$\Pi = \frac{\sigma \cos \theta}{L r (dP/dx + a \Delta p)}$$

Here σ is the surface tension, θ is the wetting angle, r , L are two characteristic length scales of the fragment under consideration, for example, the pore capillary radius and length of a drop, dP/dx is pressure (head) gradient of water flow through the reservoir, a is vibroacceleration created by external force, $\Delta\rho$ is the density difference between water and oil.

External source shows its effect when vibroacceleration is equal

$$a \sim 1/\Delta\rho \, dP/dx$$

This evaluation was tested in following lab test. Special two-dimensional model was prepared to visual study of displacement of residual oil. The model consists of glass sheets, which have canals having special form inside. These canals represent real geometry porous medium. Acoustic generator was added to one side of model and acoustic geophone was added to other side of model. Length of the model had 0.05 m, canals have cross-section 0.2x1 mm. Residual oil was created in oil saturated model by means of water filtration. Acoustic source generate high-frequency so that vibroacceleration amplitude was increased. Residual oil drops were mobilized when frequency was equal 8.6 kHz. Experimental vibroacceleration amplitude was equal 144 m/sec². It will make theoretical evaluation. Hydraulics pressures difference ΔP is equal to capillary pressure

$$\Delta P \sim \sigma/r$$

Surface tension for labs oil is equal 0.005N/m then ΔP is equal 500 N/m² (here capillary radius is equal 0.1mm).

Vibroacceleration value have following form

$$a \sim 1/\Delta\rho \, \Delta P/l$$

here l is the maximum length of residual oil drops. Visual study residual oil drops gave value equal ~ 0.02 m. Then the vibroacceleration value is 125 m/sec².

3.Theory evaluation

The criterion of mobility, which is universal, should answer the question what will be with by-passed oil with preset, for example, volume and length, put into real porous medium with known values of porosity and permeability. The universal character of the criterion of mobility of by-passed oil in porous medium should not include the parameters reflecting the value of interaction between porous medium and matter of by-passed oil. Here below is given the expression for the criterion being the result of solution of the problem of gravitational segregation of oil droplet in a hydrophilic capillary with canal taper angle, α ,

$$\Pi = \frac{V_0^{0.5} (8k/m)^{-0.25}}{2L(\pi \operatorname{tg}\alpha)^{0.5}}$$

and the problem of possibility of gravitational segregation comes to a detailed classification of residual oil in oil reservoir after water flooding.

An important conclusion following from experimental and theoretical study of mobility of by-passed oil in the elastic vibration field is that for substantial change of criterion of mobility (within tens of percents) vibroacceleration in near by-passed oil zone should be either of the order of free fall acceleration or of the order of sweep-out pressure gradient.

It is not difficult to create vibroacceleration comparable with free fall acceleration at the surface in laboratory conditions, but it is quite unreal to create it in oil reservoirs. The point is that for real values of vibration amplitudes and frequencies ($X_0 = 10^{-7}-10^{-9}$ m, $f = 5-60$ Hz)

used in areal vibroseismic action, performed by vibrator seismic energy source, the resulting values of vibroacceleration of points of medium constitute values of up to 0.1% of free fall acceleration. It is possible to create high vibroacceleration by increasing frequency and amplitude of vibrations. However when we increase frequency we drastically reduce the coverage factor of vibroaction, due to the exponential attenuation of waves with the increase of frequencies, and when we increase vibration displacement amplitude we enter the zone of nonelastic loading of rock structure in near source zone that also results in reduction of the coverage factor.

The effect of vibrations on oil production without any evident discontinuity of medium [10,11,12] indicates that the vibroaction in such a case features high frequencies and low amplitudes. The variation of oil production in producing wells

at water-flooded reservoirs located 1000 m and more from the vibration source indicates that the same behaviour is observed at these distances.

Thus real rock constituting oil reservoir converts the energy of low frequency vibrations into high frequency vibration energy prior to its conversion into heat energy. It is possible if the reservoir has modular structure.

4. Block structure of oil layers.

Experimental investigations of geological strata have shown that they consist of blocks of different sizes [13]. Special works were proved this affirmation for oil saturated formation. There were measured cores from bore 2035 of Pavlovskoe oil field. The cores were taken from depth interval 1019-1026 m. There were 1086 measurements. Frequently occurring values of cores have following sizes: 1.5;5;14;42; 3.9;26.5;82; 7,20,65 mm. Correlation between the big sizes L_{k+1} and small ones L_k was in a rather small range and changes was between 3-3.08. Analysis of layer distribution during scanning in open hole taken in metric range shows that correlation between the big block sizes and small ones changes between 2.91-3.43. They were taken from open hole N471 of Byrkinskoe oil field at the depths 809 - 1439m and from open hole N331 of Chernushinskoe oil field at the depth 829-969m.

5. Model oil saturated formation consisting of blocks different sizes.

Simple two-dimensional model of block medium represents system of blocks of different sizes. Each block with the the big size includes 3 of blocks with smaller sizes. Such dividing corresponds to experimental data of previous chapter. The block is absolutely hard, displacement of block depends on tangential and normal tensions. Tangential tension have following form $\tau = \mu U_{ty}$, here t tangential tension, μ is dynamic viscosity, U_{ty} is the velocity gradient of displacement of block in direction perpendicular to surface of block. Its evaluation is $U_{ty} \sim U_t / \delta$. Here δ is a depth of penetrating of oscillations of block.

Its value was defined in following form [14] $\delta = (2\omega/\nu)^{0.5}$. Here ν is kinematical viscosity, ω is the frequency of oscillations of blocks.

The displacement of blocks may be described in following form:

$$\begin{aligned} MU_{11} &= -2(M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}U_{11} - 2CU_1 + C(f+U_2) + (M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}(f_1 + U_{21}) \\ MU_{21} &= -2(M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}U_{21} - 2CU_2 + C(U_1+U_3) + (M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}(U_{11}+U_{31}) \\ MU_{31} &= -2(M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}U_{31} - 2CU_3 + C(f+U_2) + (M\rho^{1/2})^{2/3}(\omega\mu/2\rho)^{1/2}(f_1 + U_{21}) \end{aligned}$$

Here U_1 , U_2 , U_3 are displacements of small blocks composing big block, f is amplitude of external force, ρ is the density of blocks, C is elasticity coefficient of material of block, M is mass of block.

Analysis of equations showed that big block perform high-frequency oscillations equal 10-20 kHz when external vibration has low-frequency - 120 Hz ($M=3$ kg, $C=10^9$ N/m, $\rho=6000$ kg/m³, $\mu=10^4$ Pa.sec).

6. Field trials

The previous field experiments were conducted at the Abuzy reservoir in the Krasnodar region of the North Caucasus, water-flooded reservoirs Changyr-Tash in Kirgizstan and Zirnovskoe close to Volga-river [10,11].

Experimental works were continued at the Pavlovskoe reservoirs in the Urals.

The Pavlovskoe reservoir is being exploited from 1956. Its structure corresponds to anticlinal fold. Seismic waves act at the layer Tl_{2a} represented by sands and sandstones. The thickness of the layer Tl_{2a} is 4 m, oil-bearing layer has thickness 2.4 m at the depth 1440 m. Porosity is 22%. Permeability is 0.346 mkm² after core studies. According to geophysical data value of saturation is 0.88. Oil density is 896 kg/m³. Viscosity is 6.29 mPa.sec in the layer condition.

Water flooding began in 1964. Average water production was 82.9% on 1.01.94. Total well number is equal 47; 24 are producing wells. Total fluid production was equal to 3.1-230 ton per day, total oil production was equal 0.1-38.7 ton per day. Average fluid and oil productions were equal 43.7 and 7.4 ton per day respectively.

The work was performed at the 3 block from 25 October 1995 till 20 November 1995 through wave waveguide in the well N11. Electromagnetic hammer MEM-3000 acted at waveguide top end. The hammer created 40-55 stress pulses per minute. So the operating frequency was 12 Hz.

The background values of well rates and water percentage were measured previously. After the first cycle of vibration high increase of oil production was observed and decrease of water percentage by 5%.

6. Conclusion

Residual oil mobility depends on water rate and intensity of ultrasound oscillations generated in oil saturated formation consisting of blocks of different sizes.

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