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UDC 532.5

THE EFFECTIVENESS OF HYDRAULIC FRACTURING AT THE FIELDS WITH A ROW SYSTEM OF WELL LOCATION

ABSTRACT. This article contains the analysis of the impact of length, orientation and direction of hydraulic fracture cracks of finite conductivity on the effectiveness of oil recovery from the oil fields with a row system of well location. The analysis is based on the 3D hydrodynamic model of two-phase filtration. It is shown that cracks orientation in producing wells of a uniform reservoir has little effect on the final oil recovery efficiency. Hydraulic treatment in the second row of producers is characterized by more rapid distribution of the high reservoir pressure created by injectors across the area. For this reason, water breakthrough towards the producers of the first row is more rapid. At the same time the hydrofracking treatment in the second row of producers results in intensified oil production (oil production rate). Hydraulic fracturing performed in the first producing row would result in slower movement of the injected water and more effective reservoir depletion. Thus, the higher value of final oil recovery efficiency is achieved by hydraulic fracturing in the first producing row. Hydraulic fracturing in the second producing row is the most effective type of stimulation in terms of oil production rate.

KEY WORDS. Multiphase filtration, hydraulic fracturing, reservoir simulation, numerical methods

One of the issues of designing the systems of oil field development using hydraulic fracturing is the issue of optimal location of cracks as regards other wells of producing and pressure types. This issue was addressed in a number of publications [1, 2, 3, 4, 5, 6 7, 8]. For example, in N.A. Mousli's research [1] based on the study of a complex of two wells one of which has an ideal crack, it is shown that if the crack length is less than half the distance between two wells, its influence on the neighbouring well is negligibly small. Long X. Nghiem [2] shows that in the inverted five-spot pattern with the ideal hydraulic fracture crack in the injector well the best oil displacement results are obtained when the crack is vertical to the displacement front. V.M. Entov, V.V. Murzenko [3], V.V. Murzenko [4] on the basis of homogeneous fluid stationary filtration model analyse the influence of hydraulic fracture crack of infinite conductivity on the effective well productivity in three-row, five-spot and nine-spot schemes of well location and show that in any case the maximum efficiency is achieved if all wells are hydro fractured. R.D. Kanevskaya had a series of publications [5, 6] dwelling on the effect hydraulic fracturing has on interference in intermitting well spacing systems: five-, seven-, nine-spot or three-row. The research studies the homogeneous liquid stationary filtration model; to model a crack we introduced some reduced well radius. The results indicate that the effectiveness of hydraulic fracturing, i.e. the highest flowrate, is greater when it is used at the pressure wells only, than when it is also used at the producing wells. D.R. Deriglazov et al. [7] studied frontal advance of water-oil displacement in the three-row symmetry element with hydraulic fracturing at the producing wells. The authors showed that cracks in the first producing row in some circumstances can lead to premature water encroachment. N.S. Piskunov's research [8] examines the influence of hydraulic fracturing in the field with a certain production system on the effectiveness of oil recovery. Along with it, it is discussed an important design issue, that is the issue of how hydraulic fracturing influences spacing of wells.

This brief overview of the relevant research reveals some fundamental disagreements in their results and conclusions [2], [5], [4]. Besides, the majority of the current research is limited to stationary flow of homogeneous fluid and well productivity analysis. At the same time the influence of length, orientation and direction of hydraulic fracture cracks with regard to other wells in the conditions of non-stationary multiphase filtration on the oil recovery factor and on intensification of oil production remains under-researched. To tackle this issue, the current research studies the role of cracks length and direction in oil recovery.

We also study interference in the three-row well spacing system, which consist of two rows of injectors and three rows of producing wells (Fig. 1).

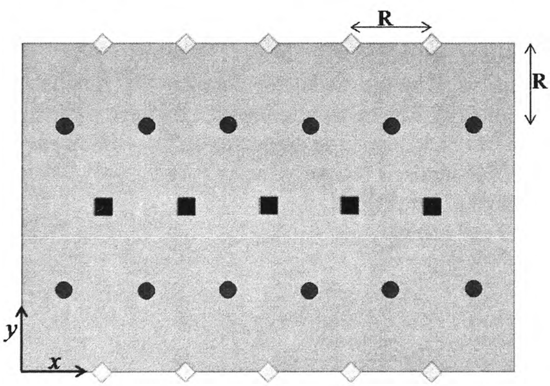

Fig. 1. General scheme of computational domain

– injector well,
– first row producing well,
– second row producing row

Table 1 demonstrates 20 different variants

Table 1

Calculated variants scheme

Azimuth / Length	L_f=1/2 R	L_f= 2/5 R	L_f= ¼ R	L_f= 1/8 R
0	1	6	11	16
30	2	7	12	17
45	3	8	13	18
60	4	9	14	19
90	5	10	15	20

The computational grid was rotated by 45° to avoid the influence of orientation. The filtration model has the following parameters:

1. Two-phase (oil, water) 3D model of reservoir 49x49x5 boxes.
2. Occurence depth 2000 m.
3. Box size 50 x 50 x 0.5 m.
4. Porosity 0.15.
5. Sand content 1.
6. Permeability 100 mD.
7. Initial conditions:
   - Pressure 200 atm.
   - Water saturation 0–0.5 units.
8. Hydraulic fracture cracks parameters:
   - Crack opening 5 mm.
   - Crack permeability 35 D.
9. Producing wells operate under BHP control (100 atm).
10. Pressure wells operate under BHP control (300 atm).

Calculations are based on the model developed in [9], which is implemented into software programme [10]. The calculations prove that in the three-row well spacing system orientation of cracks has little influence on the effectiveness of surrounding wells, the value of the final oil recovery factor varying only in the third and fourth digit after the decimal point (Fig. 2).

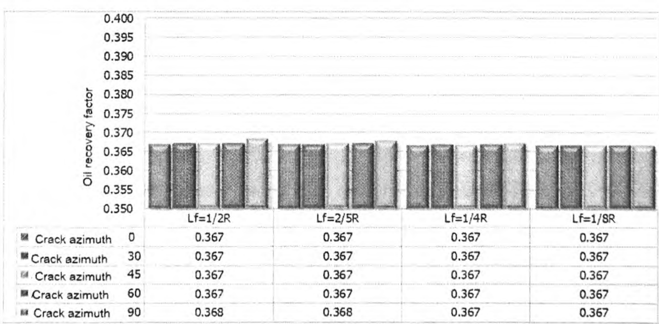

Fig. 2. The influence of hydraulic fracture cracks orientation and length on the oil recovery factor

Below there are some results of numerical solution to the water-oil displacement problem of the three-row well spacing system, with hydraulic fracturing used in all producing wells. Namely, Figs. 3–4 compare the dynamics of oil production and water cuttings from the first row of producing wells.

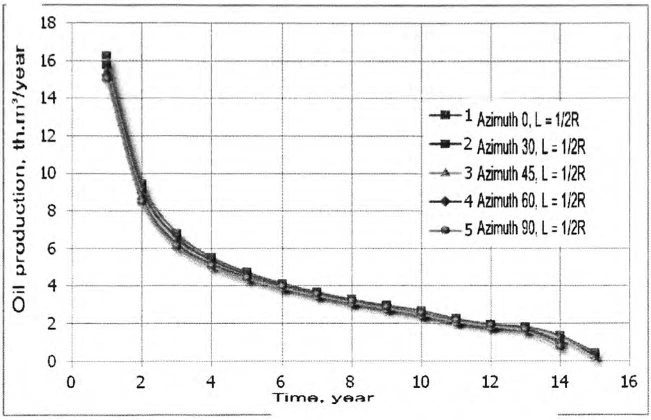

Fig. 3. The oil production dynamics from the first producing row at different azimuth of hydraulic fracture cracks

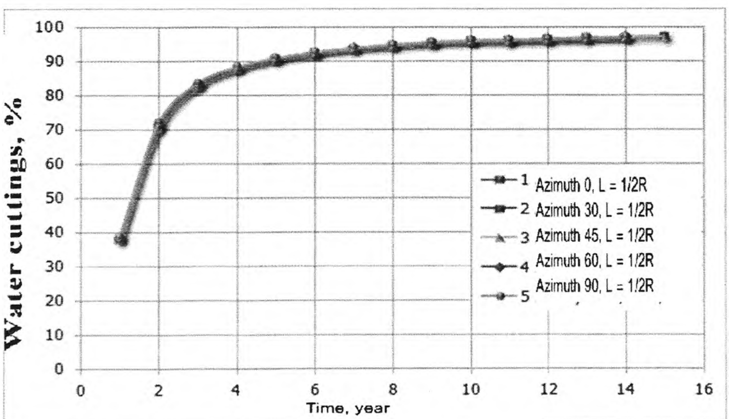

Fig. 4. The dynamics of water cuttings from the first producing row at different azimuth of hydraulic fracture cracks

Figures 5–6 contain data to compare zones of hydrocarbon saturation at 97% of water encroachment in the first row.

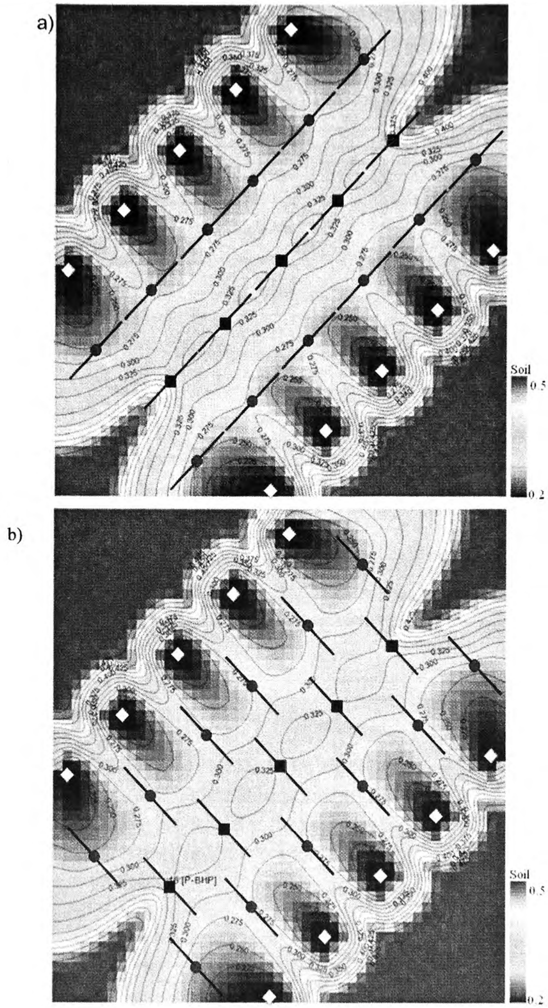

Fig. 5. Oil saturation distribution

Crack azimuth 0° (a), crack azimuth 90° (b), crack length $L_f = ½ R$

—pressure well,

—first row producing well,

—second row producing row

The issue of hydraulic fracturing effectiveness in producing rows of the three-row system seems to be more important. R.D. Kanevskaya [11], for example, argues that the use of hydraulic fracturing in the first-row producers is more effective than in the second-row producers. We have considered 20 different combinations of well spacing and hydraulic fracture cracks length (Table 2).

Table 2

Calculated variants scheme

Number of fractures / Length	L_f=1/2R	L_f=2/5R	L_f=1/4R	L_f=1/8R
No fracture basic variant	0	0	0	0
Hydraulic fracturing in all wells	1	6	11	16
Hydraulic fracturing in all producing wells	2	7	12	17
Hydraulic fracturing in the second-row producers	3	8	13	18
Hydraulic fracturing in the first-row producers	4	9	14	19
Hydraulic fracturing in all pressure wells	5	10	15	20

Calculations based on the models prove that hydraulic fracturing used in the first producing row is more effective in terms of oil flow rate; this variant does not involve rapid frontal advance of water-oil displacement from the pressure wells to the central row of producing wells unlike the variant with fracturing in the second row. Fracturing in the second row leads to decline in the reservoir pressure between the rows of producing wells and rapid water advance to the second-row wells which prematurely encroaches the first-row wells (see Fig. 6).

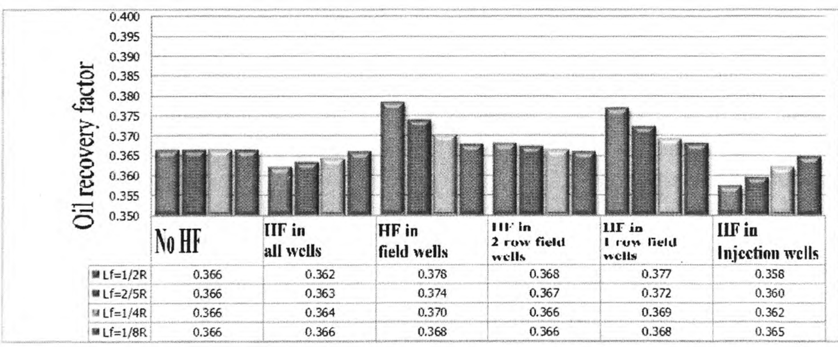

Fig. 6. The influence of hydraulic fracture cracks location and length on the oil recovery factor

Figure 7 illustrates that the scenario with hydraulic fracturing in the first-row wells has a higher oil recovery factor, but the intensification effect (oil production rate) is higher if hydraulic fracturing is used in the second-row wells rather that in the first-row wells.

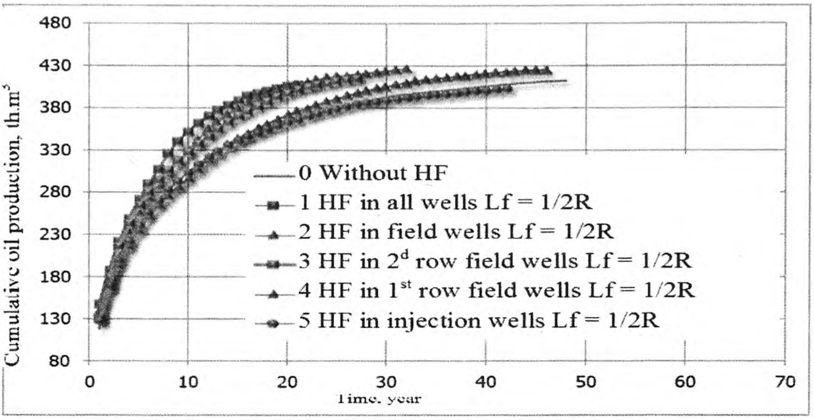

Fig. 7. Cumulative oil production at different cracks location in the wells of the three-row system

In case hydraulic fracturing is used in all the wells these two positive effects are combined, i.e. both the oil recovery factor (as with fracturing in the first row only) and the oil production rate (as with fracturing in the second row only) are increased.

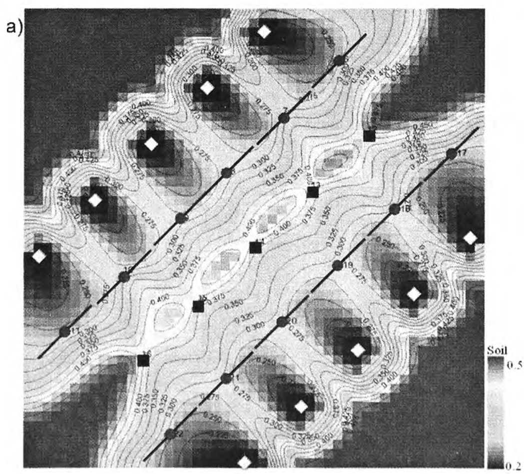

Fig. 8. Oil saturation distribution

Hydraulic fracturing in the first-row wells (a),

◇ – pressure well,

● – first-row producing well,

■ – second-row producing row

b)

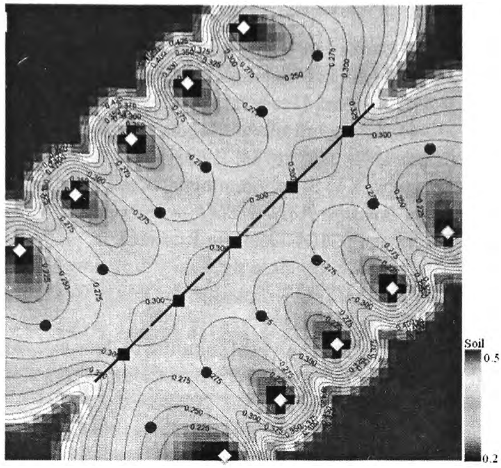

Fig. 8. Oil saturation distribution

Hydraulic fracturing in the second-row wells (b),
◇ – pressure well,
● – first-row producing well,
■ – second-row producing row

Figures 8 (a), (b) show oil saturation distribution for scenarios that involve fracturing in the first and in the second rows respectfully at 97% of water encroachment in the first-row wells.

The above maps of oil saturation distribution prove that fracturing in the second row speeds up the frontal advance of water displacement more effectively than fracturing in the first row, at the same time it also increases the amount of residual oil in the first-row wells area.

Taking into account that the effects from fracturing usually last for 1–4 years [12], of all the scenarios considered, fracturing in the second-row wells is the most effective one.

Conclusion

Vertical cracks orientation in the producing wells of a homogeneous reservoir with the three-row well spacing system of production has almost no influence on the final oil recovery efficiency.

The higher value of the final oil recovery efficiency is achieved by hydraulic fracturing in the first producing row.

Hydraulic fracturing in the second producing row is the most effective type of stimulation in terms of oil production rate.

REFERENCES

1. Mousli Naelah A., Raghavan Rajagopal, Cinco — Ley Heber, Samaniego — V. Fernando «The Influence of Vertical Fractures Intercepting Active and Observation Wells on Interference Tests» // *SPE Journal*, December 1982, Pp. 933-944.

2. Nghiem Long X. «Modeling Infinite — Conductivity Vertical Fractures With Source and Sink Terms» // *SPE Journal*, August 1983, P. 633 - 644.

3. Entov, V.M., Murzenko, V.V. Steady homogeneous fluid filtration in the oil reservoir suffering hydraulic fracture. *Izvestija RAN. MZhG — Izvestiya RAN (The Russian Academy of Science). MZhG.* 1994. №. 1. Pp. 104-1124. (in Russian).

4. Murzenko, V.V. Analytical solutions to the steady fluid flow tasks in reservoirs suffering hydraulic fracture. *Izvestija RAN. MZhG — Izvestiya RAN (The Russian Academy of Science). MZhG.* 1994. № 2. Pp. 74-82. (in Russian).

5. Kanevskaja, R.D., Kac, R.M. Analytical solutions to the tasks on the hydraulic vertical crack well inflow and their use in filtration numerical models. *Izvestija RAN. MZhG — Izvestiya RAN (The Russian Academy of Science). MZhG.* 1996. № 6. Pp. 69-80. (in Russian).

6. Kanevskaja, R.D. *Matematicheskoe modelirovanie nefti i gaza s primeneniem gidravlicheskogo razryva plasta* [Oil and gas mathematical modeling with reservoir hydraulic fracturing]. M.: Nedra, 1999. (in Russian).

7. Deriglazov, D.N., Pichugin, O.N., Rodionov, S.P. Numerical survey on the hydraulic fracture orientation impact on influx efficiency [Chislennoe issledovanie vlijanija orientacii treshhiny gidrorazryva na jeffektivnost' zavodnenija]. *Sb. tr. nauch.-praktich. konf. «Sostojanie, problemy, osnovnye napravlenija razvitija neftjanoj promyshlennosti v XXI veke».* ["Problems, state and main trends of the XXI century oil industry development" Scientific workshop materials]. Tyumen, 2000. Part 1. Pp. 134-142. (in Russian).

8. Piskunov, N.S. Formation fracturing and hydraulic fracturing impact on the field exploitation. *Trudy VNII — Works VNII.* Issue XVI. M.: Gostoptezizdat, 1958. Pp. 3-24. (in Russian).

9. Gil'miev, D.R. Water breakthrough dynamic modeling for hydrofracturing cracked wells. *Nauchno-tehnicheskij vestnik Povolzh'ja — The Volga Region Research and Technology Herald.* 2011. № 5. Pp. 27-31. (in Russian).

10. "FluxSim" software registration certificate №. 2012618782 issued Sept 9, 2012.

11. Kanevskaja, R.D., Kac, R.M. Efficiency estimate for formation fracturing in its different breakthrough systems. *Neftjanoe hozjajstvo — Oil Industry.* №6. 1998. Pp. 34-37. (in Russian).

12. Economides, M.J., Nolte, K.G. Reservoir Stimulation Englewood Cliffs, New Jersey. 1989. 430 pp.