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Novel method for fracture propagation analysis after multistage refracturing on horizontal wells

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Abstract

The problem of the refracturing treatment efficiency in relation to fracture propagation direction is considered in the study. Novel method for fracture propagation direction analysis is introduced. It is proved in the article that the stress field alteration due to pore pressure perturbation (production) can be described by temperature changes (heat flow) of solid body. Therefore, simulation study consists of simulation of fracture initiation and propagation (mechanical effect) in structural package, which add compression to the in-situ stress field, then production of fluid is simulated by means of heat flow in thermal package and finally stress field changes due to mechanical and thermoelastic effects are assessed in structural package.

Keywords: Fracture propagation analysis, multistage refactoring, stress field perturbation;

1. Introduction

Nowadays, drilling of horizontal wells becomes more and more widespread. This tendency may be explained by the development of new technologies allows reducing the capital expenditures and increasing the profit. One more reason is the fact that conventional reserves is depleting, and petroleum engineers have to develop low permeable oilfields. Therefore, in order to increase reservoir exposure and make the development economically viable multistage hydraulic fracturing is used. The number of drilled horizontal multi fractured wells increases in time.

However, despite the high production rates at the beginning of the production, most of the fractured wells are characterized by dramatic flow rates decrease in time, especially this tendency is crucial for low permeable reservoirs. Therefore, refracturing treatment is performed in order to sustain production and to produce fluid from undepleted zones between initial fractures, because it is rather cheaper then infill drilling.

According to Grissel, B. et al [2] refracturing treatment success is low (around 40-50%). It may be explained by the facts that many of the operations were performed without determination of possible fracture direction and these operations were poorly designed in relation to technological aspects (completion design, diverter agent and isolation assessment of the well). Therefore, in order to design efficient refracturing treatment two aspects: geomechanics study (stress field perturbation assessment which governs fracture propagation direction) and accurate technology design have to be taken into account.

Considering all mentioned above facts it may be stated that the problem of refracturing treatments is actual for the oil and gas industry nowadays, because the usage of multi fractured horizontal wells are becoming more and more widespread and the wells, which were fractured some time ago, needs to be refractured efficiently now.

For the purpose of the problem, solving it is necessary to establish the most accurate method for determination of direction of the fracture, which may be induced during refracturing treatment at different production time, in order to design efficient treatment.

2. Materials and methods

First of all, it is necessary to state that fracture propagation perpendicularly to the minimum horizontal stress is assumed and the part where it deviates from this path around a wellbore is small and can be neglected in the considering scale. The assumption is made because the fracture geometry in the reservoir is more important than near the wellbore and tensile fractures (mode I) are considered.

Secondly, the poroelastic displacement discontinuity method which is being used as conventional method demands writing the code solving the government equations, and visualization is questionable. Moreover, there is no available software to tackle the problem of poroelasticity without writing a code.

On the other hand, fluid flow in porous medium and heat flow in solid medium are governed by almost similar equation. Furthermore, this similarity is observed in poroelasticity and thermoelasticity [1, 3]. According to Fjaer, E. et al. [1] the continuum equation for poroelasticity:

$$\sigma_{i,j} = \lambda_{fr} e_{vol} \delta_{i,j} + 2G e_{i,j} + \alpha p_f \delta_{i,j},$$

where $\sigma_{i,j}$ – stress, Pa,
e_{vol} – volumetric strain,
$\delta_{i,j}$ – identity tensor,
G – shear modulus, Pa,
$e_{i,j}$ – strain,
pf – reservoir pressure, Pa,
$\lambda_{fr} = \lambda - \frac{C}{M}$,
C and M - elastic moduli,
λ - Lame parameter.
And the continuum equation for thermoelasticity is:

$$\sigma_{i,j} = \lambda_{fr} e_{vol} \delta_{i,j} + 2G e_{i,j} + 3\alpha_T K \Delta T \delta_{i,j},$$

where K – bulk modulus, Pa,
α_T – coefficient of thermal expansion, °C-1,
T – temperature, °C.

In such a way, the similarity is evident: the pore pressure changes induce the similar stress perturbation as temperature changes and $\alpha = 3K\alpha_T$. It is necessary to point out, that the equivalent measurement units have to be used.

Considering the diffusivity equation for fluid flow:

$$\frac{dP}{dt} = \frac{k}{\mu \phi c_t} \frac{d^2 P}{dx^2},$$

and for heat flow:

$$\frac{dT}{dt} = \frac{k_T}{\rho C_p}\frac{d^2T}{dx^2}$$

where k – permeability, m2,
μ – fluid viscosity, Pa·s,
ϕ – reservoir porosity,
c_t – total compressibility of the system, Pa-1,
k_T – thermal conductivity, W/(m·°C),
ρ – reservoir rock density, kg/m3,
Cp – heat capacity, J/(kg·°C),
the similarity between fluid flow and heat flow diffusion constant can be observed: $\frac{k}{\mu\phi c_t} = \frac{k_T}{\rho C_p}$.

Consequently, the stress field alteration due to pore pressure perturbation (production) can be described by temperature changes (heat flow) of solid body. Mechanical effects of fracture initiation and propagation can be considered in any software.

Therefore, simulation study consists of simulation of fracture initiation and propagation (mechanical effect) in structural package, which add compression to the in-situ stress field, then production of fluid is simulated by means of heat flow in thermal package and finally stress field changes due to mechanical and thermoelastic effects are assessed in structural package. The workflow of the simulation is presented in the figure 1.

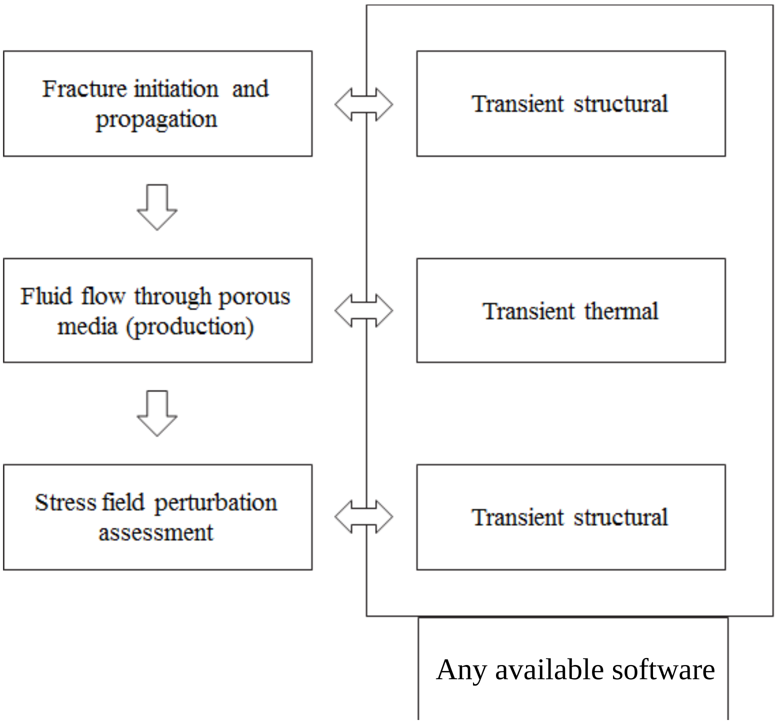

Figure 1 – Simulation workflow

The following input must be entered:

- for mechanical study: in situ principal stresses, hydraulic fracturing pressure which will be added to the fracture plane, mechanical properties of the reservoir (Young's modulus and Poisson's ratio);
- for thermoelastic study: coefficient of thermal expansion (analogue of Biot coefficient), thermal conductivity and specific heat (analogue of fluid diffusivity) and heat flow (fluid flow which is taken from production history of the well).

It is necessary to state that the definition of maximum and minimum stresses in the classical mechanics and geomechanics are different: the maximum stress is where the body constrained to maximum extension, whereas in geomechanics maximum stress is where the body is constrained to the maximum compression.

3. Results

Since the method of stress field perturbation is novel the simulation is performed for the assessment of stress field perturbations around a vertical well in order to verify the method discussed above and then for horizontal well.

The main assumptions of the work are:

- the reservoirs have isotropic properties (mechanical, permeability, porosity etc.);
- the bottom-hole pressure is distributed equally along the vertical section;
- the pressure during the fracturing treatment which leads to fracture initiation and propagation is act equally along the whole fracture plane;
- the fractures initiated during the initial fracturing treatments are planar (they have lined xy plane cross-section).

After the model is build and initiated the mechanical effect of fracturing is simulated, the quarter of the space around the wellbore is considered to reduce the calculation time.

The observed simulation results are similar to Rezaei, A. results [4] The stress reversal expansion is favorable for vertical well direction because if the induced fracture during refracturing propagates perpendicularly to the initial fracture it will drain undepleted zones. But it is necessary to select the time when the radius of stress reversal region reaches the designed fracture length, and this region is not depleted sufficiently. For this purpose, the assessment study of stress reversal region with production time is performed (figure 2).

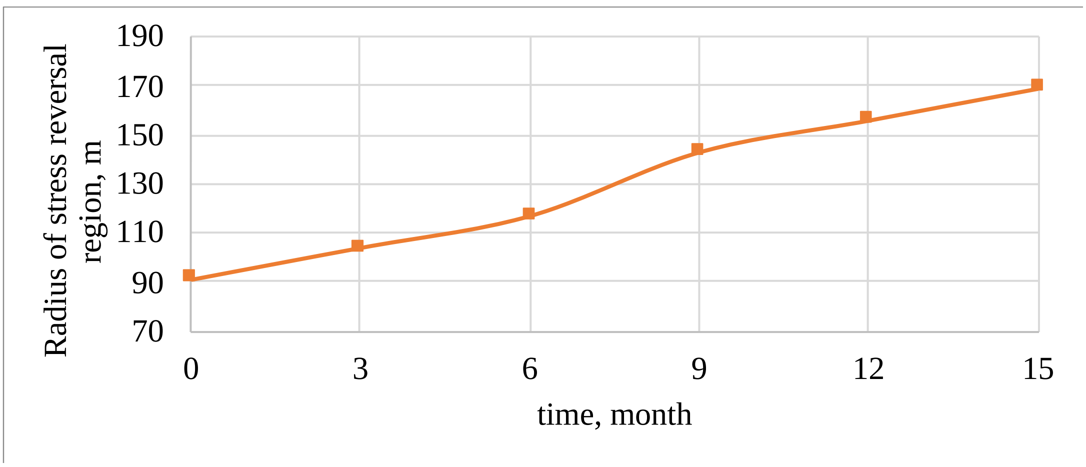

Figure 2 – Simulation results

By means of the assessment, the optimal time for refracturing, at which the second fracture will propagate perpendicularly to the first one. Analysis of fracture propagation during multistage refracturing can be performed in a similar way, but the following must be assumed additionally:

- the horizontal wellbore section of well is drilled along the SHmax direction;
- the bottom-hole pressure is distributed equally along the horizontal section of the wellbore, therefore, each fracture drains equal volume of the fluid.

4. Conclusion

To sum up, it may be stated:

- the capability of stress field perturbation due to poroelastic effect simulation by means of heat flow is introduced and validated;
- the point of time from which the refracturing treatment will be efficient in vertical well can be determined and the actual time of refracturing is selected by two considerations: secondary fracture will propagate perpendicularly to the initial and the initial fracture has drained optimal reservoir volume;
- if the refracturing is planned in the well, it has to be designed at the step of well planning, in order to select optimal distance between stages of the initial treatment and appropriate well completion to initiate fractures in defined point.

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