Simulation of Fracture Conductivity Changes Due to Proppant Composition and Stress Cycles

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Abstract

Properties of proppant affect hydraulic fracturing design results. The one of the most important goals of stimulation is to obtain fracture with high and viable conductivity. Bulk density and the grains size are factors that the most influence fracture conductivity. Regarding proppant, the common point of view is, that only mesh size and type of proppant (bulk density, crush rate) have influence on hydraulic fracturing efficiency. Paper presents computer simulation results of conductivity reduction caused by stress changes. Calculations were done for the same proppant type and size but with different grain compositions. It shows influence of average diameter of proppant grains and bulk density variation on fracture conductivity. It was found that the most important factor is number of stress cycles. Higher stress cycle number results in significant fracture conductivity reduction.

Keywords: computer simulation, hydraulic fracturing, proppant

Introduction

Many factors influence final fracturing efficiency result. For this reason computer simulation is useful tool to investigate such complicated process.Fracpro by StrataGen Engineering, Inc., a part of the Carbo company, is one of the most popular simulators for the design and analysis of hydraulic fracturing. Fracpro's many-sided portfolio provides unparalleled fracture design, analysis and monitoring capabilities that enable production optimization and economic performance. The software can effectively design every type of stimulation job, including vertical wells and fracturing in horizontal wells. It is possible to model fracture growth in any formation like: carbonate, shale, sandstone and even coal. Fracpro permits to understand proppant placement, changes in fracture conductivity and fracture dimensions. The software has the capability to merge the effects of proppant damage due to crushing, embedment, stress cycling, non-Darcy and multiphase flow. It can simulate both single and multiple treatment horizontal wells. Special displays allow to plainly visualize fracture placement alongside the lateral [9].

Application of real data gives engineers the opportunity to better understand their well's response, with resulting procedures that reflect the reality of what is occurring in the reservoir, before, during and after fracturing treatments. The 3D fracture model or pseudo-3D model, properly represents the level of complexity and reality of hydraulic fracturing. It also allows to design 2D models of fracture geometry (PKN, KGD, radial). Fracpro software is able to model almost unlimited combinations of well configuration, fracture dimensions and proppant placement. It enables designers to capture data in real-time [9].

Proppant

It is known, that propping agents with greater size contribute to obtaining conductive fracture. Larger proppant has better conductivity, but the proppant size affects treatment design[8]. However, the space between pores within the proppant pack need to be free of particulates from crushed propping material under the influence of cyclic stress[3, 4].Proppant settling is connected with Stokes law related to the proppant diameter squared[8]:

$$V_S = [(2(\rho_P - \rho_F)) / 36\,\mu]\, gD^2 \quad (1)$$

where:
V_S – settling velocity, m/s,
g – gravitational acceleration, m/s2,
ρP – proppant density, kg/m3,
ρF – fluid density, kg/m3,
μ – dynamic viscosity, Pa·s
D – diameter of proppant grain, m.

Settling of proppant in fracture affects its conductivity. According to Harrington et al. [2], 20/40 mesh sand with an average proppant grain diameter of 0.61 mm will settle 4.5 times faster than 40/60 mesh sand with an average proppant grain diameter of 0.31 mm. However, this calculation does not include the effects of hindered settling. Proppant size is also important in perforation design and settling especially in small fractures. Larger grains shall build high porosity proppant layer [8]. In fact,impurities causes a lot of snags like susceptibility to crushing, fines migration and blocking the pores, what results in decline of fracture and proppant pack conductivity[1].

Bulk density of a proppant is a ratio of its mass and its volume including the contribution of the void volume. It may be expressed in kilograms per cubic meter (kg/m³) but petroleum industry is using usually lb/ft3. The bulk density influences the way of transport and proppant distribution in the hydraulic fracture. Application of propping material with high bulk density causes some problems with proppant suspension in fracturing fluid. Under influence of gravity the proppant grains settle down earlier, before they reach the

Tab.1. Geomechanical data used in simulation
Tab. 1. Dane geomechaniczne użyte w symulacji

Layer	Closure Stress Gradient [Pa/m]	Young Modulus [GPa]	Poisson's Ratio
Shale	$1.697 \cdot 10^4$	41.37	0.25
Sandstone	$1.516 \cdot 10^4$	27.58	0.20

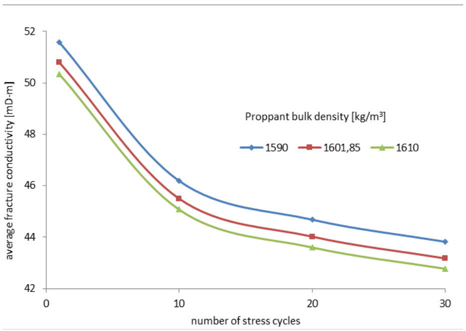

Fig. 1. Average fracture conductivity vs. number of stress cycles for different proppant bulk density
Rys. 1. Średnia przewodność szczeliny w funkcji liczby cykli naprężenia dla różnych gęstości objętościowych

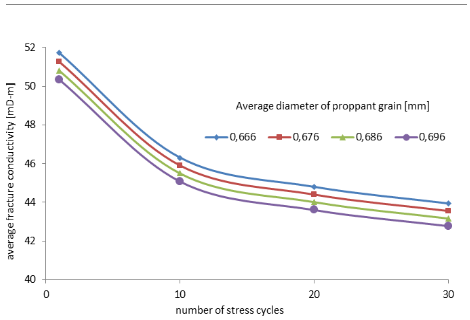

Fig. 2. Average fracture conductivity vs. number of stress cycles for different average diameter of proppant grains
Rys. 2. Średnia przewodność szczeliny w funkcji liczby cykli naprężenia dla różnych średnich średnic ziarna propantu

total volume of a generated fracture. Hence, less conductive fracture may be obtained.

Computer simulation

Computer simulation was done to check if the same proppant size and type can result in diffferent fracture conductivity depending on its composition.In the same time stress cycles were simulated to check influence of well operations on final average fracture conductivity.The research how proppant properties such as bulk density and average size of material particles affect fracture conductivity after 30 stress cycles was conducted in Fracpro software.The single pseudo 3D vertical fracture with lumped parameters was designed ina tight sandstone layerat depth of approximately 2400 m, with geomechanical properties shown in Table 1. Production zones were isolated by layers of shale.

Following data were used for simulation: injection rate -0.05 m³/s , dimensionless conductivity goal -10.0, selected minimum fracture half-length - 60 m, maximum proppant concentration -20.0 ppg. As a fracturing fluid Versagel was assumed.Temperature has important influence on the near wellbore region and tubing [5,6,7] as well as on the fracture propping. Taking it into account reservoir temperature wasassumed 90°C and reservoir pressure 24 MPa.

In order to examine influence of proppant bulk density on fracture conductivity, three variants of proppant Atlas PRC Premium 20/40 mesh were applied. The first with bulk density of 1590 kg/m³, the second with standard bulk density of 1601.85 kg/m³ and the third with bulk density of 1610 kg/m³.

In terms of influence of average proppant grains size on fracture conductivity next four variants of proppant Atlas PRC Premium 20/40 mesh were examined. The average diameter of proppant grain was from 0.666 mm to 0.696 mm with step 0.01.

Other data applied for computer simulation: stress cycle exponent -0.05, turbulence coefficient aat low stress -1.02, turbulence coefficient bat low stress- 0.05, turbulence coefficient aat high stress -1.18, turbulence coefficient bat high stress -0.08.

Figure 1 shows that, for the same proppant type and mesh size, only change in composition resulting in the proppant bulk density changes is affecting fracture conductivity. The higher bulk density of proppant, the lower fracture conductivity is obtained. It is caused by settling proppant grains in a time of the stimulation. According to the equation (1), heavier grains settle more rapidly due to gravity and often form a proppant bank near the wellbore. As a result, hydraulically created fracture is not fully propped. In addition, the curves describe influence of cyclic stress on conductivity of fracture. Cyclic stress reduces average fracture conductivity.

The same commercial proppant type and size can be distributed with different composition depending on the manufactured unit. Grains compositions influence its average diameter. For this reason was performed simulation of fracture propagation and fracture propping effect using Atlas PRC Premium 20/40 mesh with different average grain diameters. It was found that increase of average proppant diameter results in decreasing tendency of fracture conductivity (Figure 2). Application of bigger proppant grains leads to reduction of conductivity. Larger proppant grain settle down faster due to its weight. In addition, the influence of stress cycling was examined. As before, the higher number of stress cycles, the less conductive fracture is.

Conclusions

- Settling phenomenon during hydraulic fracturing process plays important role. Even for the same type and mesh size of the proppant, small bulk density decreaseby its grain composition results in the more conductive fracture.
- Opposite to common point of view, for given proppant mesh size, the largeraverage grains diameter results in the less conductive fracture.
- Among investigated parameters, stress cycling prove to be the most important factor reducing fracture conductivity.

Acknowledgments

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Symulacja zmian przewodności szczeliny spowodowanych składem propantu i cyklicznym naprężeniem

Rezultaty projektowania zabiegu szczelinowania hydraulicznego są uzależnione od właściwości propantu. Jednym z najważniejszych celów stymulacji jest uzyskanie szczeliny o możliwie wysokiej przewodności. Czynnikami, które mają największy wpływ na przewodność są: rozmiar ziaren propantu i jego gęstość objętościowa. Czym większa gęstość objętościowa tym niższą przewodność szczeliny można uzyskać. Natomiast większe ziarna pozwalają na uzyskanie wyższej porowatości i lepszej przewodności. W artykule przedstawiono wyniki symulacji komputerowej pokazujące wpływ zmian naprężenia na obniżenie przewodności. Obliczenia przeprowadzono dla tego samego typu i rozmiaru propantu ale o zmiennym uziarnieniu. Wykazano wpływ gęstości objętościowej i średniej średnicy ziarna propantu na przewodność szczeliny. Stwierdzono, że najważniejszym czynnikiem jest liczba cykli zmian naprężenia. Wzrost liczby cykli powoduje znaczne obniżenie przewodności szczeliny.

Słowa kluczowe: symulacja komputerowa, szczelinowanie hydrauliczne, propant