Extension of Unified Fracture Design (UFD) Concept to Naturally Fractured Formations

Introduction

Hydraulic fracturing has become an essential stimulation technique, especially for unconventional formations. Increasing the effectiveness of hydraulic fracturing requires careful selection of design parameters to achieve a certain fracture width and half-length. However, available optimization approaches assume the existence of the hydraulic fractures only, which is inaccurate in the case of natural fractures occurrence. Hence, assessment of the complex fracture network is crucial to examine the potential impacts on the production.

The most widely accepted unified fracture design (UFD) concept assumes the square reservoir in which a vertical well is located in the centre of the reservoir, and the hydraulic fracture extends to the opposite sides by the same length, called the fracture half-length ($x_f$). The method implies that for any proppant number (Np) which is the weighted ratio of the propped volume of fracture to the volume of the reservoir, there exist such a combination of fracture length and width that maximize the dimensionless productivity index (JD). However, the UFD concept does not consider the effect of natural fractures. Therefore, the optimum dimensionless number (CfD) derived from the assumption made, which is equal to 1.6, may deviate in the case of natural fractures.

The main objective of the proposed study was to extend the conventional UFD method to come up with a new dimensionless number that includes the effects of the natural fractures. Impacts of natural fractures spacing and their dimensions (length and width) on the productivity and optimum CfD values have been analysed utilizing a self-generated reservoir simulator. Initially, to ensure the correctness of the selected methodology, the simulator was used to reproduce an already verified results with hydraulic fractures only. After that the same methodology was applied by including natural ones. Obtained results satisfied the intuitive expectations that natural fractures alter the optimum dimensionless number.

Fracture propagation

Propagation of the hydraulic fracture in the medium where naturally occurred cracks exist in the formation significantly differ from conventional cases (Potluri et al., 2005). Common fracture design methods assume a homogenous rock system without natural fractures where fractures develop symmetrically in the direction of maximum horizontal stress. However, in naturally cracked systems, the propagation happens asymmetrically, which results in complex fracture networks. Numerous analytical and numerical models are available in the literature which can be used to describe the propagation of induced fractures in the presence of natural fractures like Blanton (1982), Warpinski & Teufel (1987), and Renshaw & Pollard (1995). The geometry of created fractures differs from the conventional bi-winged planar geometry as a consequence of interactions. There are three possible fracture propagation scenarios, illustrated in Figure 1, which arise while fracturing: a) crossing natural fracture b) propagating until the junction with natural fracture and then starting to expand (dilate) in the direction of natural fracture c) expanding natural fracture and crossing after.

![Figure 1 Interaction of induced and natural fractures (Pankaj & Li, 2018)](image-url)
Productivity

Pankaj & Li (2018) conducted a case study on the Permian basin to examine the impact of natural fractures on productivity. The natural cracks located far from the stimulated region are observed to have a minor and major effect during late and early time production respectively since the conductivity of the fractures decreases over time under the impact of horizontal stresses. Wang et al. (2019) set the pseudo-steady-state productivity model and extend UFD to the complex fracture network targeting maximum productivity index. According to the study, secondary fractures would play a significant role when primary fractures have infinite conductivity without the proppant number effect. However, considering the proppant number effect, the optimum productivity will reach maximum when the relation between fracture complexity and conductivity is optimized as in one of the combinations:

1. Minimum fracture complexity, Large fracture spacing, Small proppant number.
2. Maximum fracture complexity, Small fracture spacing, Large proppant number.

Makedonska et al. (2020) used the discrete fracture network (DFN) modelling technique to study how the dimensions and stages of the induced fractures and the intensity of the natural fractures affect the deliverability of the well. In general, it was observed that in the case of the sparse natural fractures network, the performance of the well is impaired because of poor connectivity between the hydraulically induced and natural fractures.

Methodology

The sensitivity analysis was conducted for the two cases: first, only hydraulic fracture was available, whereas, in another, the complex system of hydraulic and natural fractures was simulated. The different ranges for the proppant number were defined as being low (0.01 < Np < 0.1), intermediate (0.1 < Np < 1) and high (1 < Np < 20). The range for optimum dimensionless conductivity numbers was selected to be from the relevant Np number up to 30. From the expressions that relate the Np with the CdI and penetration index Ix, the required inputs for the simulator which are fracture length, width (wF), and the fracture conductivity (kfwF) were found, and the corresponding dimensionless productivity index JD was estimated. The same procedure was repeated for all Np numbers. For both scenarios, the same reservoir parameters such as permeability, length, width, and thickness were considered, and the assumptions were made that the hydraulic fracture fully penetrates the thickness of the reservoir (hfrac = hres) and the proppant could only be transported to the hydraulic fracture while natural fractures cannot accept proppant. In case of the presence of the natural fractures, they were spaced along the length of the hydraulic fracture using the fixed interval length and oriented perpendicularly to the main hydraulic fracture as shown in Figure 2. The effect of various factors, such as length, width, spacing (natural fracture system density) on the UFD output and the productivity was investigated.

Figure 2 Spacing of natural fractures along the hydraulic fracture.
Hydraulic fracture alone scenario

This scenario was simulated to validate the selected approach for the sensitivity analysis and construction of the JD – CfD curves. According to the established concept of the UFD, for low Np number, the optimum CfD at which the maximum productivity is achieved is about 1.6 and with the increase in Np number, the optimum CfD deviates from the stated number. The same trend was confirmed by our simulation for the case with the presence of hydraulic fracture only as represented in Figure 3.

Results for this scenario confirmed the relevance of the selected approach for the sensitivity analysis and using the same procedure the second scenario with the incorporation of natural fractures system was analysed.

Sensitivity for the system of hydraulic and natural fractures

The same procedure was conducted to construct the JD – CfD curves for the reservoirs with the natural fracture system. A similar trend as for the case with a single hydraulic fracture was noticed. For the low proppant numbers, the optimum CfD values were around 0.6. The increase in Np also resulted in the shifting of optimum CfD values.

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**Figure 3** The JD – CfD curves for various Np values for hydraulic fracture alone case.

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**Figure 4** The JD – CfD curves the range of Np values for case with natural fractures.
According to the sensitivity analysis conducted for the higher Np numbers, the optimum dimensionless fracture conductivity was found to be equal to the corresponding Np number. The JD – CfD curves for various proppant numbers in the range 0.01 – 20 are illustrated in Figure 4. The subsequent step for the sensitivity analysis was the investigation of the impact of dimensions (length and width) of the natural fractures and their spacing distance (density of natural fractures system) on the productivity and the shape of the generated JD – CfD curves.

Conclusions

Based on the sensitivity analysis provided, it was figured out that the UFD concept can be applied also to the hydraulic fractures that are created in the reservoir with natural fractures. Based on the generated curves, that represent the relationship of dimensionless productivity index and dimensionless fracture conductivity, it was observed that as for the case without natural fractures, there exists such an optimum value for CfD, for which the maximum productivity can be achieved. When natural fractures are absent, this value is around 1.6 for low proppant number values. When the natural fractures are incorporated, this optimum CfD value becomes 0.6. For both cases, the increase in Np values increases the optimum CfD value. Moreover, the sensitivity analysis for the length of natural fractures showed that it has an impact on JD values, but the productivity still appears to be maximum at a value equal to 0.6 for low Np numbers.

References


