UQ Centre for Natural Gas

Multiple Fracture Growth in Modified Zipper Fracturing

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Introduction

In recent years, hydraulic fracturing technologies have been widely developed to enhance oil and gas recovery from unconventional resources (Zhou et al., 2019). Low-permeability and porosity are the main characteristics of unconventional resources, where hydraulic fracturing technologies such as horizontal multi-stage hydraulic fracturing, zipper-frac (ZF), and modified zipper-frac (MZF) have been used (Figures 1 and 2) to boost the ultimate recovery from such resources (Zhou et al., 2019).

ZF and MZF technologies have significant effects on the geometry of hydraulic fractures, such as fracture width and length. These effects do not appear to be well understood by the scholars as a result of insufficient research efforts and the challenging nature of the problem. To achieve a successful modified zipper-fracturing and to avoid any operational problems e.g., proppant bridging or screen-outs, crossing multiple fractures and multiple-fracture closure, operational parameters e.g., flow rates, injection time or period, and multiple-cluster and well spacing should be systematically analyzed prior to the fracturing operation (Saberhosseini et al., 2019; Saberhosseini et al., 2021).

Method and objective

In this work, a fully coupled two-dimensional XFEM-Cohesive Zone Model (CZM) in combination with Phantom Node Method (CPNM) was used in ABAQUS to investigate the initiation and propagation of multiple hydraulic fractures with ten injection clusters distributed in two horizontal boreholes (Figure 1). The goal of this research is to assist fracturing design in achieving a minimal deviation in multiple fractures propagation and creating deeper and much wider fractures between two horizontal boreholes of Modified Zipper Fracture completion pattern. The growth of a hydraulic fracture in an XFEM region was firstly verified by KGD zero toughness solution wherein a very good agreement with a negligible error of less than 2.5% was obtained (Figure 3). A series of simulation scenarios were then accomplished with various flow rates and three well spacings of 40m, 60m, and 80m, in a long period of injection to identify the optimum injection time in which a fracture can grow straight with any minimal deviation.

Model geometry and XFEM meshing

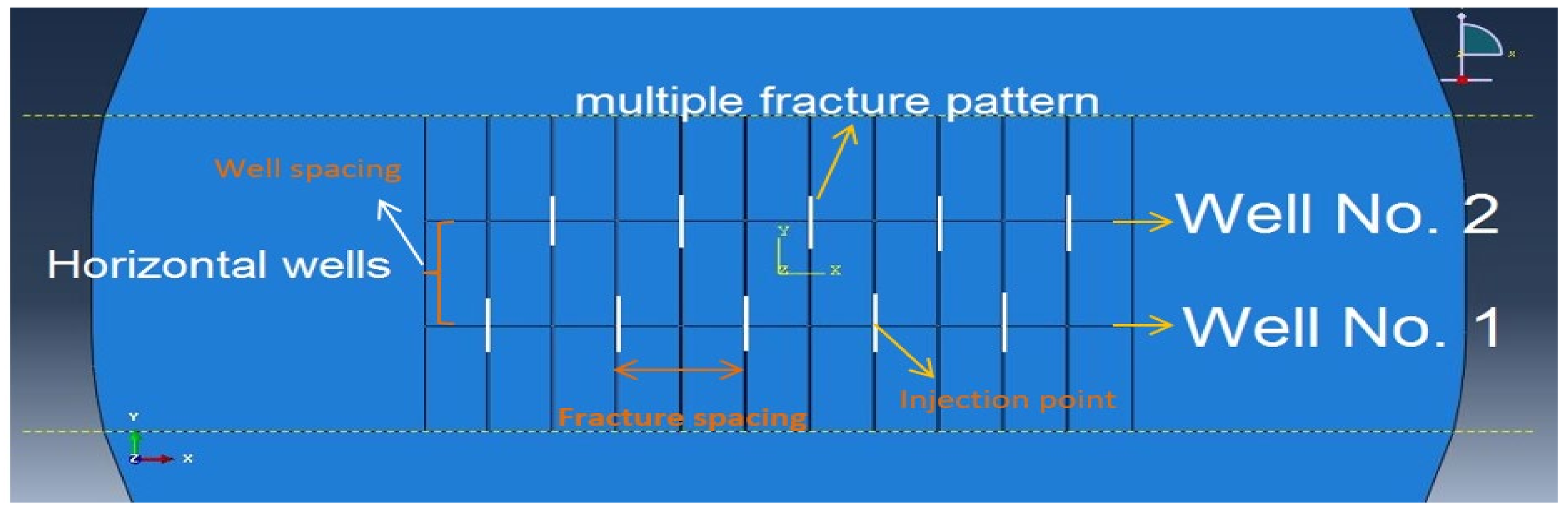

Figure 1: Geometry, multiple clusters and wells patterns of the MZF modeling

Multiple hydraulic fracturing, zipper and modified zipper fracturing

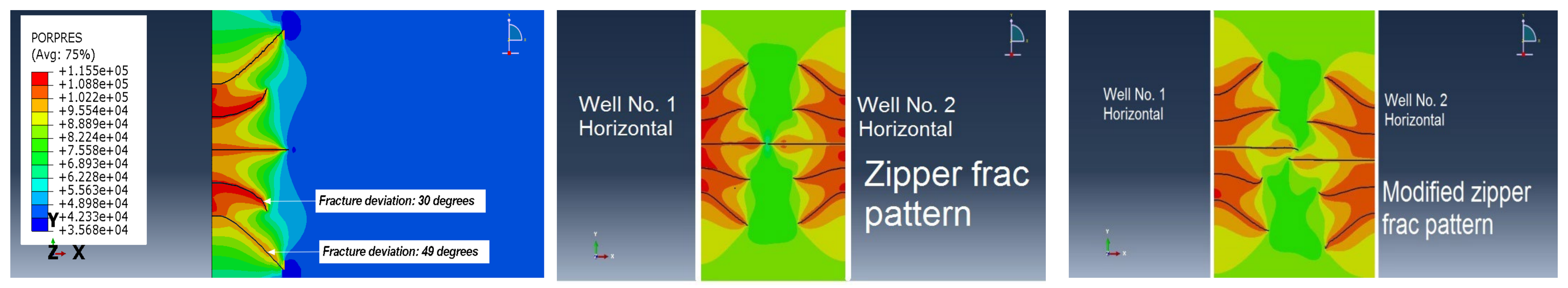

Figure 2 (a): Multiple fracturing (b): Zipper fracturing (c): MZF fracturing

Figure 2: Propagation of multiple, zipper and MZF fractures

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Results

Verification of the XFEM fracture propagation with KGD M-vertex solution

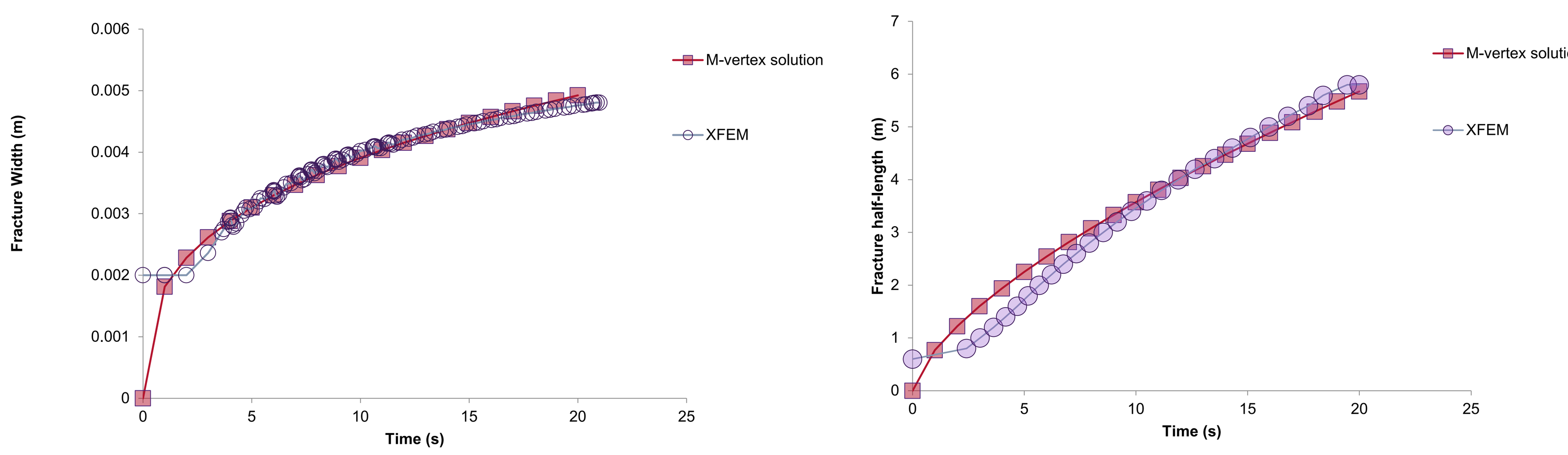

Figure 3: Propagation of hydraulic fracture width and length versus injection time

Optimum fracture spacing in MZF

As shown in Figure 4, as fracture spacing increased from 5 to 75 m, the stress shadows and pore pressure between multiple fractures reduced significantly, which resulted in the creation of deeper, wider, and straighter multiple hydraulic fractures. Therefore, 75 m spacing between injection clusters can be the optimum spacing for the MZF operation in this study.

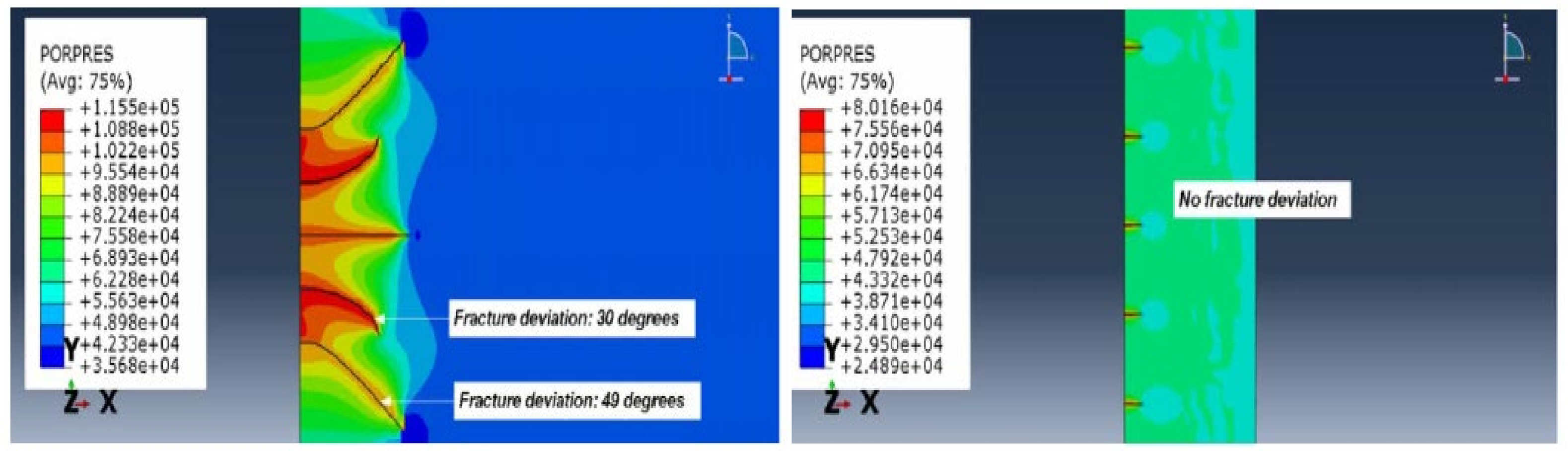

Figure 4: Multiple fractures propagation based on undesired (left) and optimum (right) fracture spacing

Possibility of multiple fracture deviation and closure in MZF operation

Multiple hydraulic fractures might come together when propagating if the spacing is tight, injection time is sufficiently high, and two wellbores are close to each other. These are undesirable outcomes. As shown in Figure 2(b and c), the fracture and well spacings were 5 m and 40 m, respectively. Multiple fractures come together after injections of 1,200 s at 0.001 m3/s flow rate, in ZF and MZF. This highlights the possibility of closure and crossing of fractures in this case. Therefore, the duration of the injection should be optimal to gain straight, and long multiple hydraulic fractures in MZF operations (Figure 5). In addition, the flow rate should be optimized further to achieve wider fractures and avoid proppant screen out. Otherwise, the well spacing should increase further to avoid the crossing of fractures during the injection when maintaining the injection time and flow rate optimal.

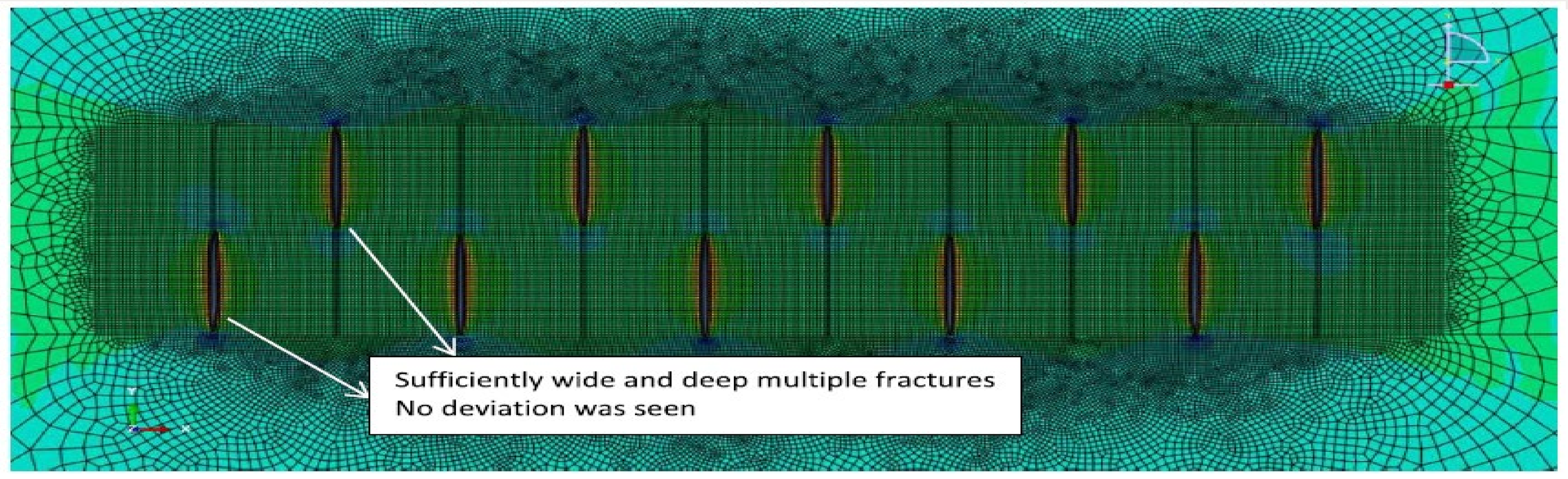

Figure 5: Multiple fractures propagation based on undesired (left) and optimum (right) fracture spacing

Abbreviations

- XFEM: Extended Finite Element Method
- KGD: Kristianovic-Geertsma-de Klerk solutions
- CPNM: Cohesive Phantom Node Method

Acknowledgements

The authors would like to thank Dr. Zuorong Chen from CSIRO Energy, Australia, for his constructive suggestions during the development of this research work.

Investigation of multiple hydraulic fractures' growth and geometry in MZF operation

A set of sensitivity analyses was run to investigate the effects of well spacing and fracture spacing. If 75 m spacing between multiple clusters is the optimum fracture spacing, it is necessary to estimate the injection time and flow rate in which multiple hydraulic fractures are propagating straight with a wider aperture and no deviation problems. The well spacing was 40 m (Table 5). Three hydraulic fracturing injection rates of 0.001, 0.002, and 0.003 m3/s were analyzed to generate constant length fractures with no deviation (i.e., 21.6 m). The results showed that the ultimate time for an injection of 0.001 m3/s was 1,200 s and it produced fractures 11.24 mm wide. Based on the results given in Table 1, the injection rates of 0.002 and 0.003 m3/s required 650 and 418 s respectively to provide the desired length of 21.6 m, which led to wider fractures of 13.29 and 14.12 mm. Therefore, a flow rate of 0.003 m3/s produced the best sets of fractures based on the desired length of 21.6 m and had wider fractures as given in Table 1 and Figure 6.

Table 1: Growth parameters of multiple hydraulic fractures

Well spacing (m)	Multiple fracture spacing (m)	Sequential fracture spacing (m)	Injection rate at injection clusters (m^3/s)	Ultimate injection time (s)	Optimized fracture length (m)	Optimized fracture half-length (m)	Optimized fracture width (mm)	Fracture deviation until the equivalent time
40	75	37.5	0.001	1,200	21.62	10.81	11.24	No
			0.002	650	21.62	10.81	13.29	No
			0.003	418	21.62	10.81	14.12	No

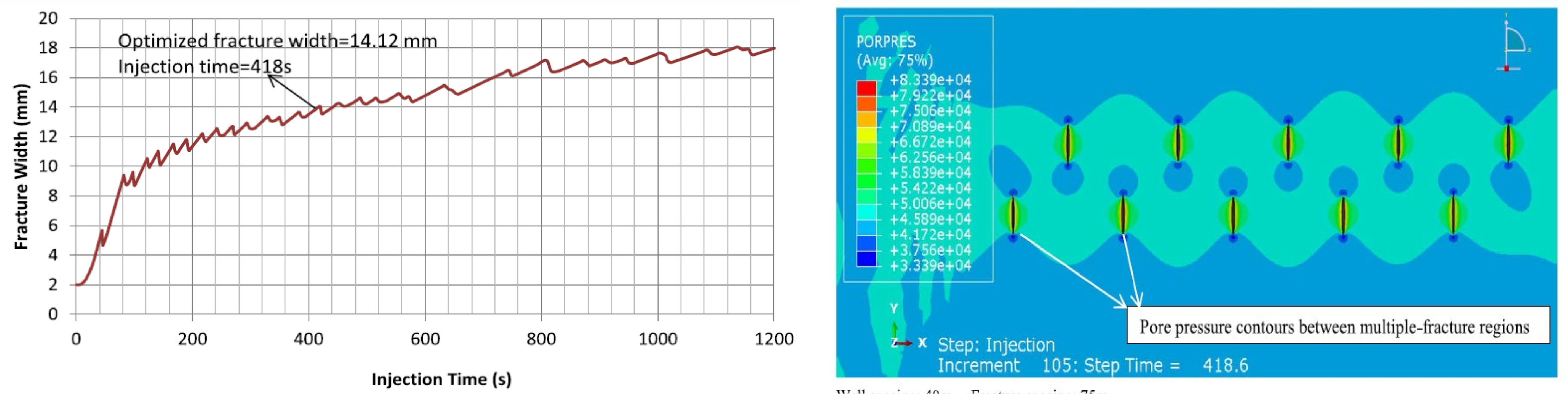

Figure 6: Multiple fractures propagation based on optimum injection time and fracture spacing

Conclusions

- The propagation of a hydraulic fracture in an XFEM region is in good agreement with the KGD M-vertex solution (zero-toughness solution) with a negligible error of 1.7%.
- The results show that by considering flow rate 0.001 m3/s for this pattern of MZF "well spacing=40m and fracture spacing=75m", the ultimate time for injection is 1200 s, in which multiple hydraulic fractures are grown straight with minimal deviation. The results also show that by increasing injection rates to 0.002 m3/s and then 0.003 m3/s, the injection time reduced from 650 s and 418 s respectively. An incremental pattern was observed for these cases where the multiple fracture width increases from 11.24mm to 13.29mm and finally 14.12mm. It's worth mentioning that the multiple fracture length remains at the constant value of 21.62 m regardless of the flow rate values. The same pattern was gained for the other two well configurations "well spacing=60m and 80m; fracture spacing=75m".
- For any patterns of MZF operation, any increase in flow rates leads to increasing multiple fracture width, whilst the ultimate time for injection should be adjusted in order to prevent multiple hydraulic fracture deviation and collision during the operation.
- The numerical model developed in this work can be directly extended to simulate similar technical challenges associated with MZF operation, and these findings can assist in optimizing MZF fracturing design via proper controls of flow rates and injection time.

References

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