Effect of Frac Interactions on Future Re-fracturing and EOR Operations

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Frac-driven Interactions (FDI)s in Horizontal Wells

- Interactions between closely-spaced fractures in the same well (intra-well), or between fractures in adjacent offset wells (inter-well) are unavoidable and a fact of life in unconventional reservoirs
- In addition to present well operations, existence of FDIs impacts future production enhancement ops, such as re-frac'ing and EOR
- Analysis of FDIs can provide very useful engineering information about the created fractures, completion quality, and guidelines for improving future well operations

Classification of FDIs

Intra-well

- Interactions between adjacent fractures in the same horizontal well
  - Important but difficult to detect & usually ignored by the industry at this time

Inter-well

- Interaction between fractures in adjacent horizontal wells
  - Can cause detectable well & production damage & subject of most industry attention at this time
  - Can also provide very useful information about engineering properties of the created fractures

Intra-well FDIs

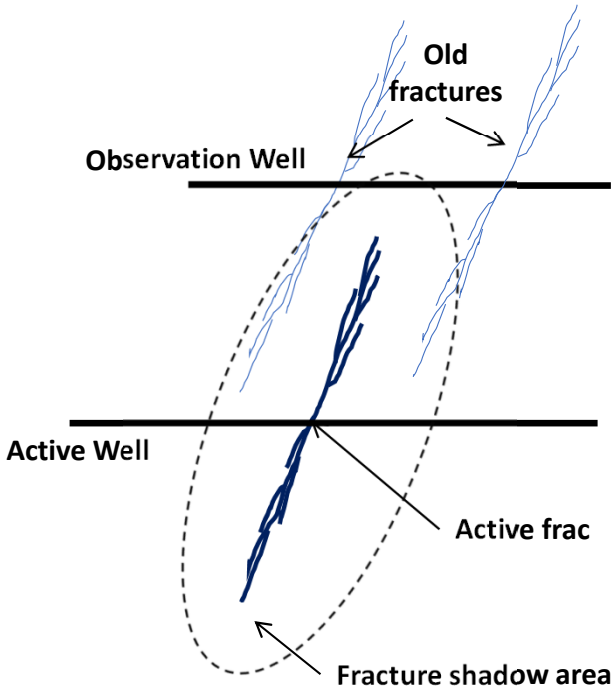
Main causes of intra-well FDIs are;

- **Initiation of axial fractures. Most fractures initiate as axial at the perforations and re-orient away from the well to become perpendicular to minimum principal stress. Joining of axial fractures from adjacent perf clusters at the wellbore can link them to each other**
- **Inadequate zonal isolation. Poor quality cementing job, or lack of isolation with packers or bridge plugs**
- **Dynamic Active Fracture Interactions (DAFI). Stresses induced by multiple simultaneously growing fractures change their extension pattern and may even cause their coalescence and reduce the number of extending fractures**
- **Natural Fractures. Open or activated natural fractures can also create a link between adjacent hydraulic fractures**

Classification of the Types of Inter-well FDIs

- **Fracture shadowing**: minor pressure increase in the passive shut-in well caused by extension of adjacent active fractures
  - No fluid migration between the two wells
- **Frac/frac connection**: larger pressure increases in the passive shut-in well caused by migration of fluid from the active fractures into the passive well/fractures
  - **Temporary connection**: fluid migration from the active fracture into the passive well stops at the end of pumping the frac stage
  - **Long-term connection**: the connection between the two wells is conductive and allows longer time fluid movement between them

Fracture Shadowing

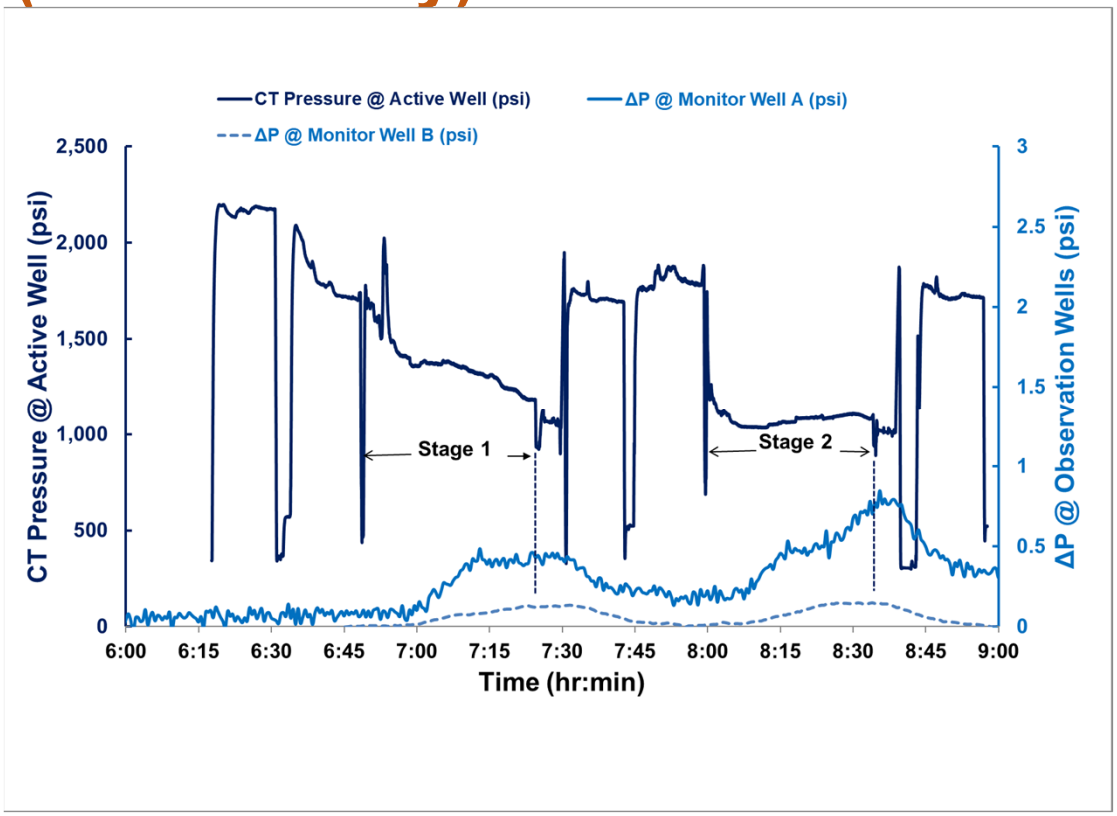


Pressure inside the active extending fracture compresses the fluid in the passive fractures in the adjacent shut-in passive monitor well

There is no direct fluid migration between the fractures

Fracture Shadowing
(Case History)

- No fluid migration between the three offset wells during the stage
- Difference in the magnitude of frac shadow pressures indicates differences in the locations of monitor well fractures relative to the active well & growth pattern of the active fracture



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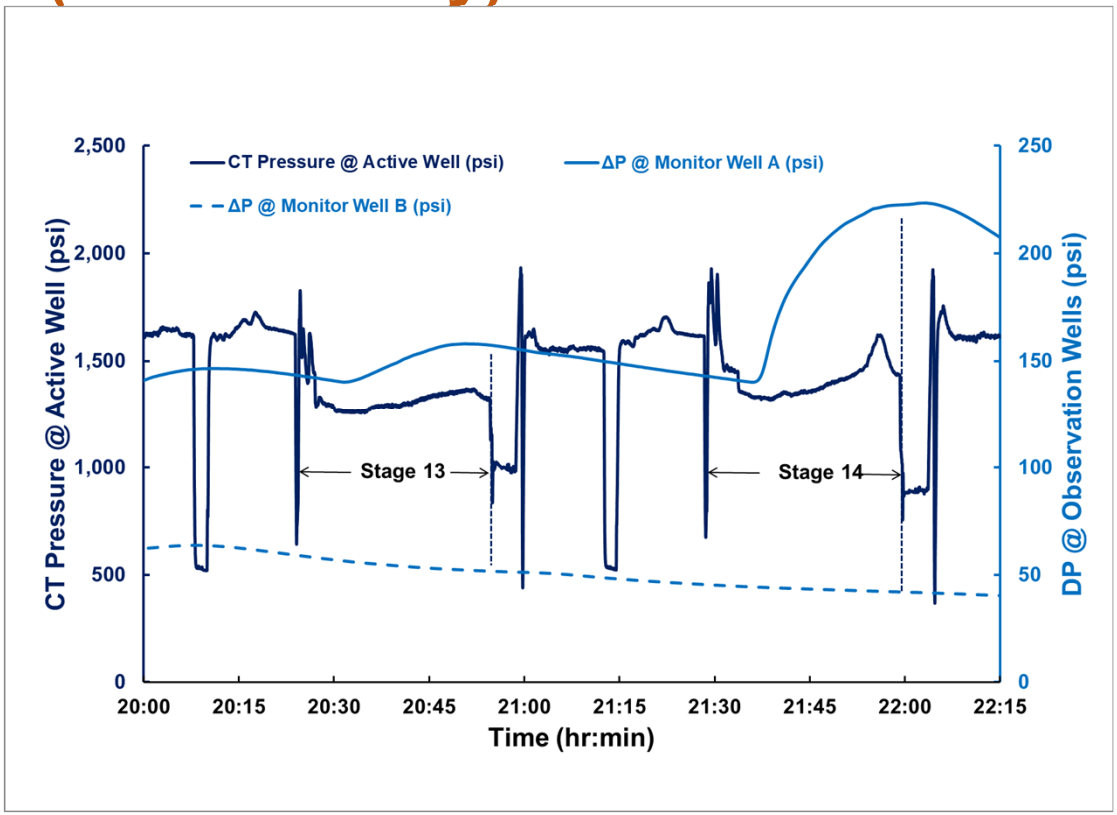
Temporary Frac/frac Connection
(Case History)

- Data from later stages in the same well
- Different interaction types in the two monitor wells caused by their relative locations & active frac growth pattern
  - Temporary frac/frac connection in well A
  - Frac shadowing in well B



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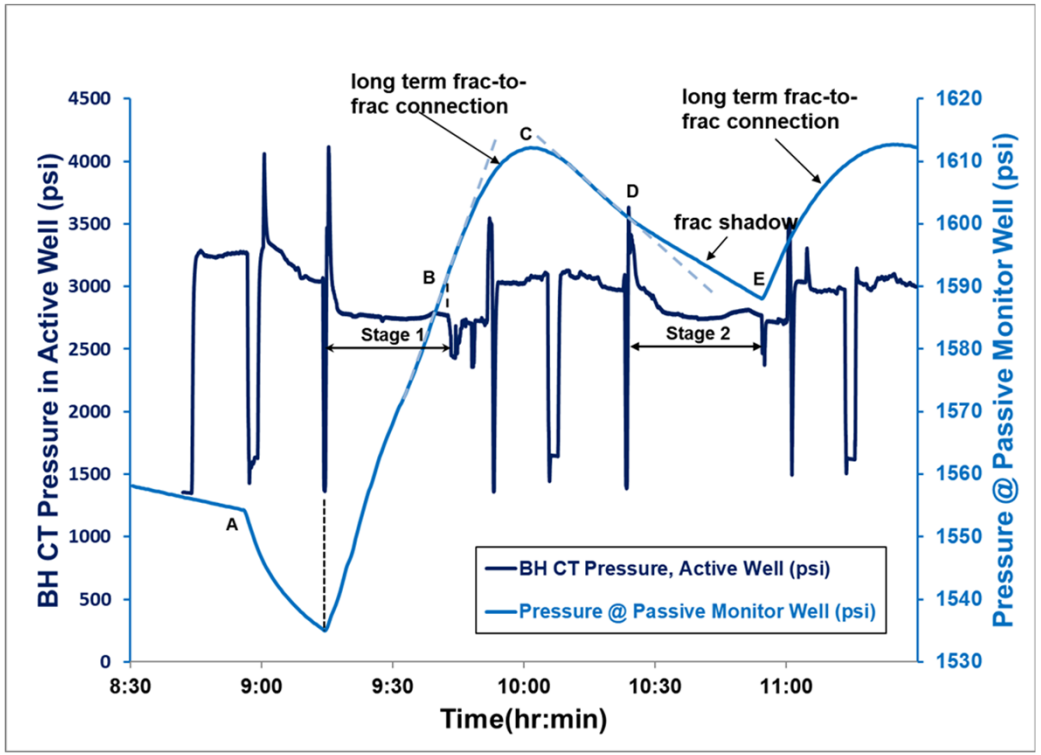
Long-Term Frac/frac Connections
(Case History)

- Active well perforated inside an existing passive well frac
- Passive/monitor well pressure increases several tens or hundreds of psi
- Hydraulic link between the two wells continues beyond the end of pumping that stage
- This type of interaction may be repeated several times in different stages, but not be present in every stage



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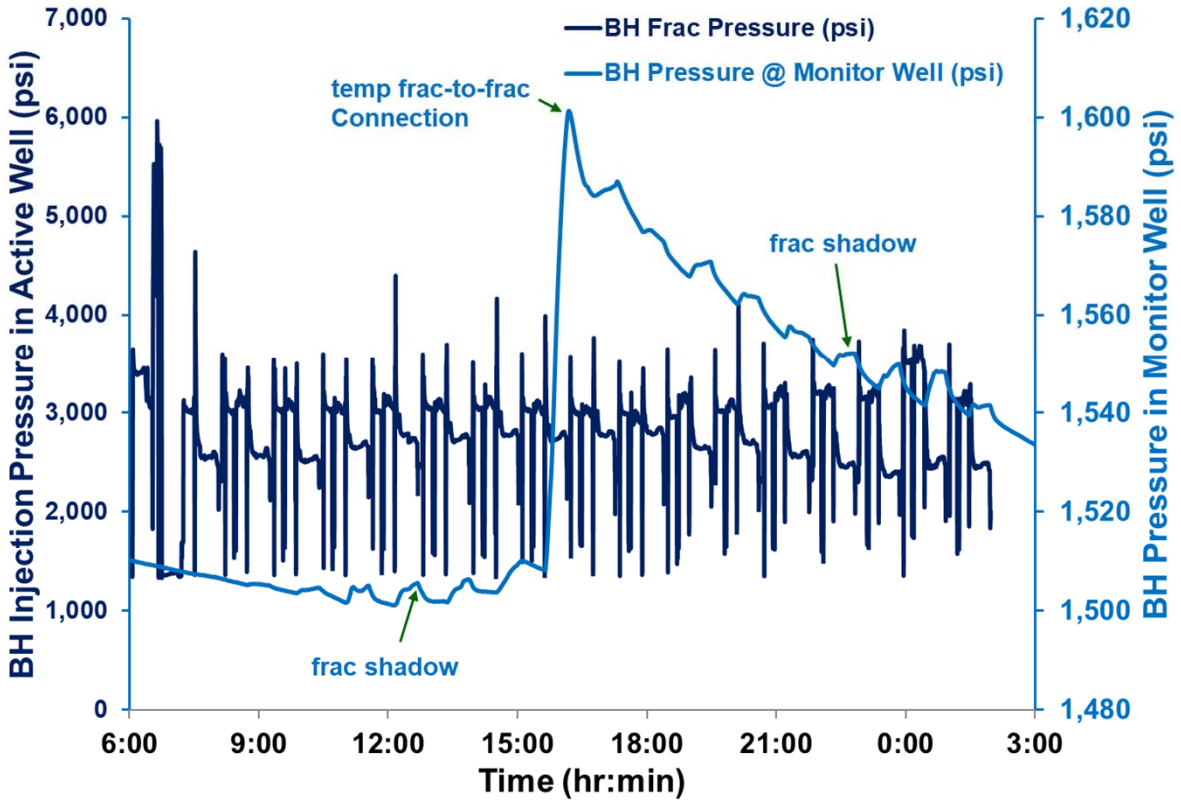
Types of FDIs in Each Well

- **Multiple types of DSI are usually present between adjacent fractured horizontal wells. Their type depends on the relative locations of opposite adjacent fractures in these wells and differences in frac treatments and pressures. While pressure data provides conclusive evidence for the presence and intensity of these interactions, it does not conclusively establish fluid migration between them. Liquid tracers are more suitable for this purpose.**

Example Case History



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Effects of Different Types of Existing FDIs for Re-frac & EOR Operations

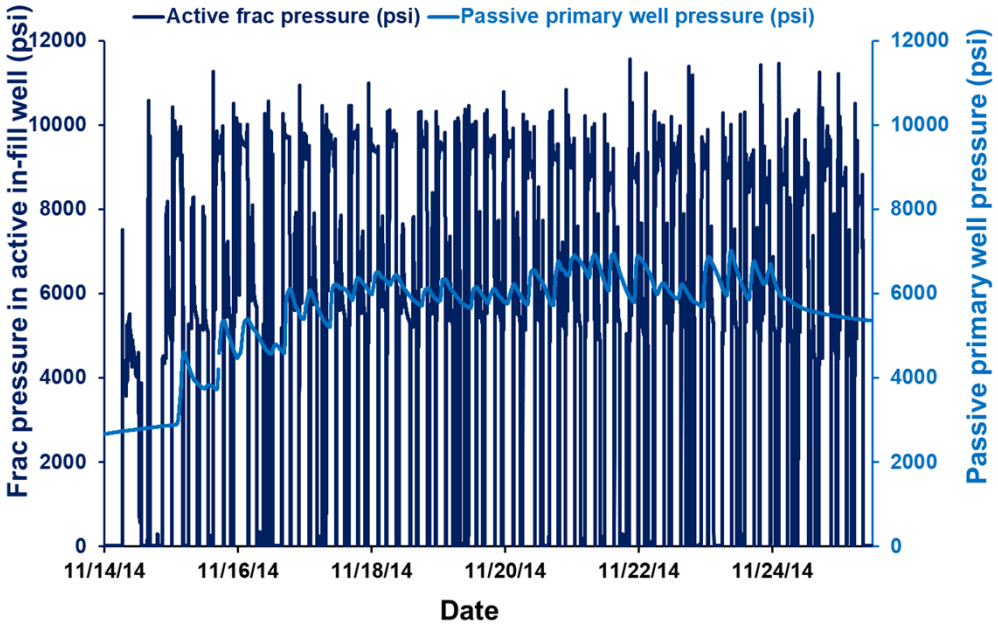
- **Frac shadowing. No direct fluid flow between the active and adjacent passive wells**
  - **Could help improve sweep efficiency of EOR operations**
  - **Minor, if any, effect on re-fracturing as long as fluid migration is avoided while re-frac'ing**
    - **Monitoring offset well pressure while re-frac'ing can provide the needed data**

Effects of Different Types of Existing FDIs on Re-frac Operations

Temporary or Long-term Fluid Migration

- **Fluid moves from the active well into the adjacent passive wells thru the connected fracs**
  - **In some cases this type of FDIs is known to have caused extension of fractures in both wells**

FDIs Causing Extension of Fracs in Both Wells (Case History)



Frac-driven pressure build-up in the shut-in offset well caused extension of its existing fractures

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Effects of Different Types of Existing FDIs on Re-frac Operations

Temporary or Long-term Fluid Migration

- Fluid migration from the active into the passive well reduces the effectiveness of re-frac operations

Corrective Action

- Based on liquid tracer results obtained during the initial frac jobs, identify the frac stages where fluid migration had occurred
- In the well which was the source of fluid migration, isolate and close-off the well section containing the connected fractures
  - Liner patches, spot cementing, ….
- Another solution is to cement a new liner inside the well before it is re-fractured

Effects of Different Types of Existing FDIs on EOR Operations

Temporary or Long-term Fluid Migration

- Fluid migration from the active into the passive well causes a fluid bypass and reduces the sweep efficiency

Corrective Action

- Based on liquid tracer results obtained during the initial frac jobs, identify the frac stages where fluid migration had occurred
- In the well which was the source of fluid migration, isolate and close-off the well section containing the connected fractures
  - Liner patches, spot cementing, ….
- Control fluid injection pressure to stay below frac pressure

Conclusions & Recommendations

- Detecting and establishing the types and intensities of FDIs between adjacent wells needs to be an integral part of well operations at all times
- Combination of pressure and liquid tracer data can help identify the type of FDI during each frac stage
- Access to, and careful analysis of, this data can serve as a guide for future well and production operations