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An Overview of Well Construction and Well Integrity Related to Hydraulically Fractured Wells – Talib Syed, TSA, Inc.

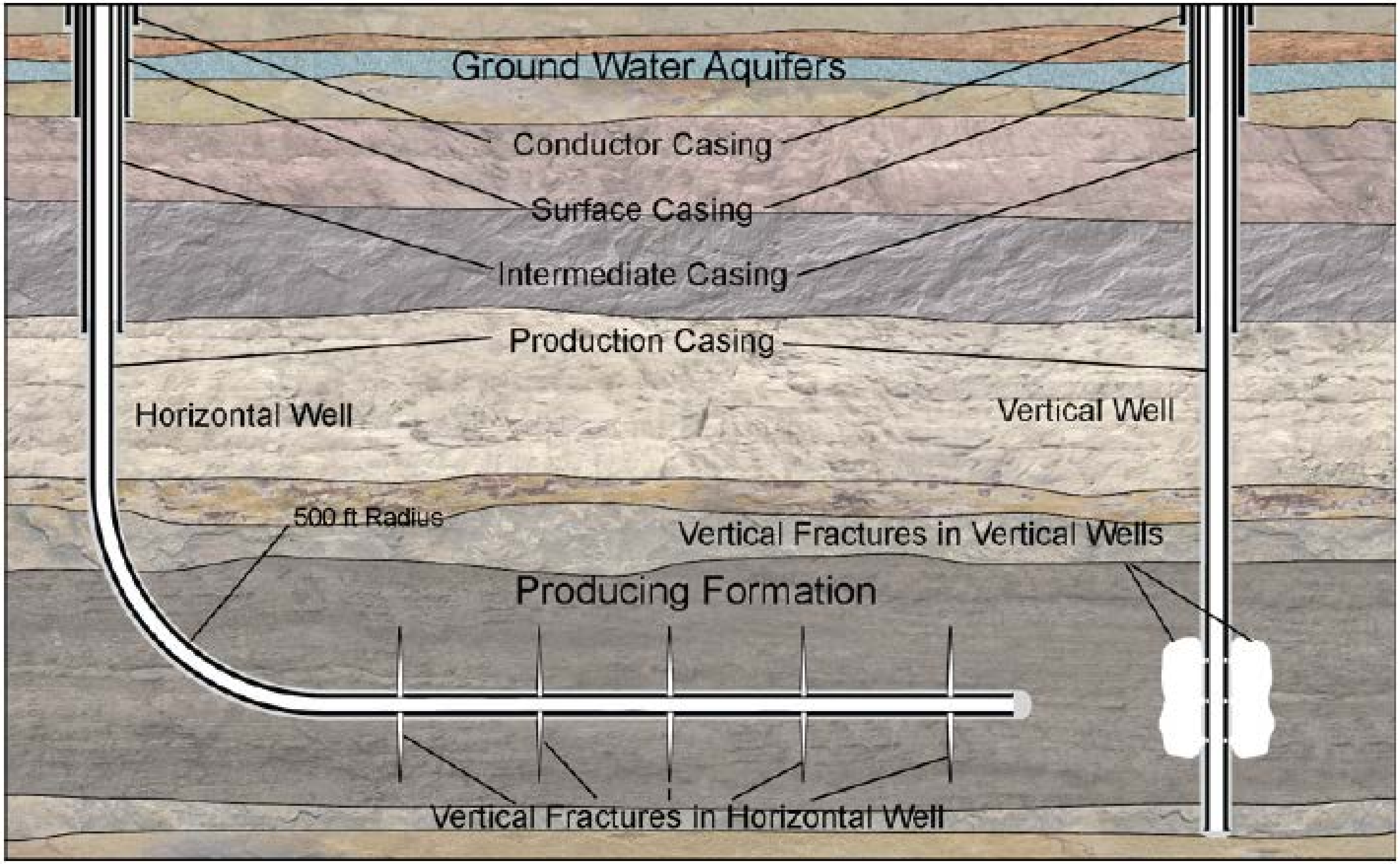

Figure 1 – Example of a Horizontal and Vertical well (API, 2009)

EXAMPLE WELLBORE SCHEMATICS – HYDRAULIC FRACTURE COMPLETIONS

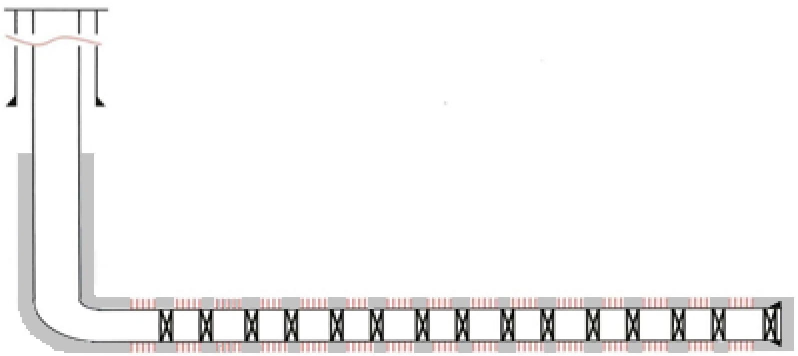

FIGURE 2

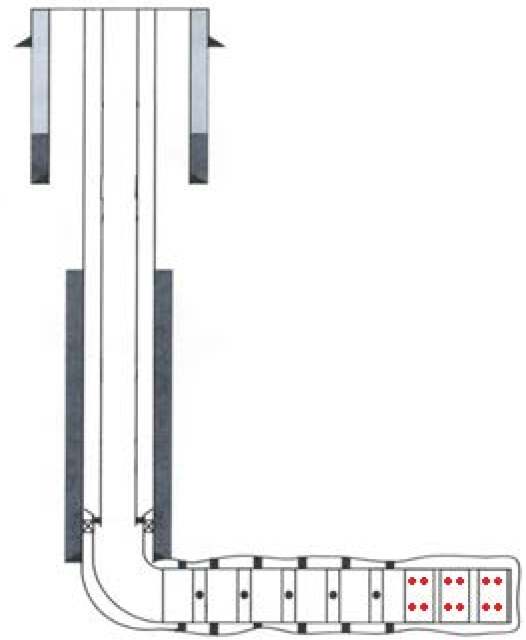

FIGURE 3

Casing Design Criteria

<u>Tensile Forces:</u>

- Tensile forces in casings originate from casing-own-weight, bending forces and shock loading. In casing design, the uppermost joint is considered weakest in tension (as it has to carry the total weight of casing string)

<u>Collapse Pressure:</u>

- Originates from the mud column used to drill the hole and acts on the outside of casing (due to drilling fluid or cement slurry)
- Since hydrostatic pressure of mud column increases with depth, collapse pressure is highest at bottom and zero at top
- Collapse pressure C, never exceeds the collapse resistance of casing.

Casing Design Criteria

Burst Pressure:

- Burst pressure normally based on max. formation pressure expected during drilling of next hole section
- Also, assumed that in the event of a kick, the influx fluid(s) will displace the entire drilling mud, subjecting the entire casing string to the bursting effects of formation pressure
- At the top of the hole the external pressure due to the hydrostatic head of mud is zero and the internal pressure must be supported entirely by the casing body. Therefore, burst pressure is highest at the top and least at the casing shoe. In situations where production tubing leaks gas to the casing, the burst pressure at the shoe can be higher than the burst pressure at the surface

Casing Design Criteria

<u>Compression Load:</u>

- Compression load arises in casings that carry inner strings. Production strings do not carry any compression load, since they do not carry inner strings
- Other loadings (accounted for using safety factors except pipe wear due to running wire-line tools and drill string assembly):
  - bending with tongs during make-up
  - pull-out of the joint and slip crushing
  - corrosion and fatigue failure
  - pipe wear due to running W/L tools and drill string assembly,
  - additional loadings from acidizing, fracturing, squeeze cementing

Casing Design Criteria: Buckling, Piston and Thermal Effects

- Buckling results when casing is unstable (e.g. partially cemented – higher probability in deviated/horizontal wells)
- Piston force is due to the hydrostatic pressure acting on the internal and external shoulders of the casing string
- Thermal effects refer to the expansion or shortening of the casing string with increase or decrease in temperature
- Since max tension and burst pressures occur at top while max collapse pressure is at bottom, a combination string is utilized – strong and heavy casing at surface, light but strong casing in middle and heavy casing at bottom.

Cement Evaluation with Acoustic Logs

- Acoustic cement bond logs do not measure hydraulic seal but instead measure loss of acoustic energy as it propagates through casing. This loss of energy is related to the fraction of casing perimeter covered by cement. Cement Bond Log (CBL) has one omni-directional transmitter & receiver.
- The Ultrasonic Imaging Tool (USIT) is a continuously rotating pulse-echo type tool with nearly 100% coverage of the casing wall (acoustic impedance – Z).
- The Segmented Bond Tool (SBT) measures the quality of cement effectiveness, vertically and laterally around the circumference of the casing in 6 segments around the pipe. SBT is usually run with VDL (variable density log).

Factors affecting CBL/USIT tool performance

- *Microannulus* is a very small (annular gap) between casing and cement sheath and can result in misinterpretation of CBL/VDL. Generally, pressure up casing to 1000 to 1500 psi to close the gap (if cement job was good). Ultrasonic tools less affected than CBL/VDL and SBT (pads) in the presence of liquid in the gap with opposite effect in the presence of gas.
- *Eccentralization* a potential concern in deviated/horizontal wells due to absence of cement on the low side and small distance between casing and formation face.
- *Logging Tool Centralization* is mandatory for USIT and CBL/VDL tools. The SBT pads with articulated arms are unaffected, although the CBL/VDL part may be affected.
- *Fast Formations* – acoustic signals from some formations reach the receiver ahead of pipe signal. Fast formations affect the CBL/VDLs/SBT logs but do not affect USIT interpretation.
- *Lightweight Cement* – lack of contrast in acoustic properties between lightweight (used in weak formations) and regular cement slurry.
- *Cement Setting Time* – important for CBL interpretation. If run too early before cement is set, may indicate poor bonding and an unnecessary squeeze operation. Use UCA (ultrasonic cement analyser) to determine WOC time and when to log.

Problems in Cementing Horizontal Wells

- Hole cleaning and drilling-fluid displacement
  - Avoid low-side channels (may not seal annulus) and control drilling fluid properties within specific ranges
  - Pipe movement (reciprocation/rotation) is beneficial
- Centralization of pipe
  - Proper use of mechanical cementing aids
  - Correct number of centralizers and minimize drag
- Optimizing cement slurry designs
  - Prevent free water in slurry – can form water channel and allow migration of frac/reservoir fluids
  - Use ASC (acid-soluble cements) for isolation between perf stages and reduce near wellbore friction (NWF), skin effects
- Evaluation with acoustic tools – CBL/USIT/Interpretation challenges and access in lateral sections.

Zonal Coverage, Top of Cement (TOC) Determination and Casing Shoe Isolation

- Well construction and local regulations determine extent of cement coverage
  - Surface casing cemented to surface (top job option)
  - Intermediate/production casing may or may not be cemented to surface (unintended fracturing of weak formations)
  - Important to cover all zones that have potential to flow. Zones left un-cemented may not flow in short-term but may lead to SCP (sustained casing pressure) over long term
  - Cement top selection dependent on potential flow zones, regulatory requirements and pore pressure/fracture gradient
  - Pressure tests to confirm isolation at shoe (formation integrity test/leak-off test, pump in test - FIT/LOT/PIT) – squeeze job if needed with follow-up LOT/FIT

Well Integrity

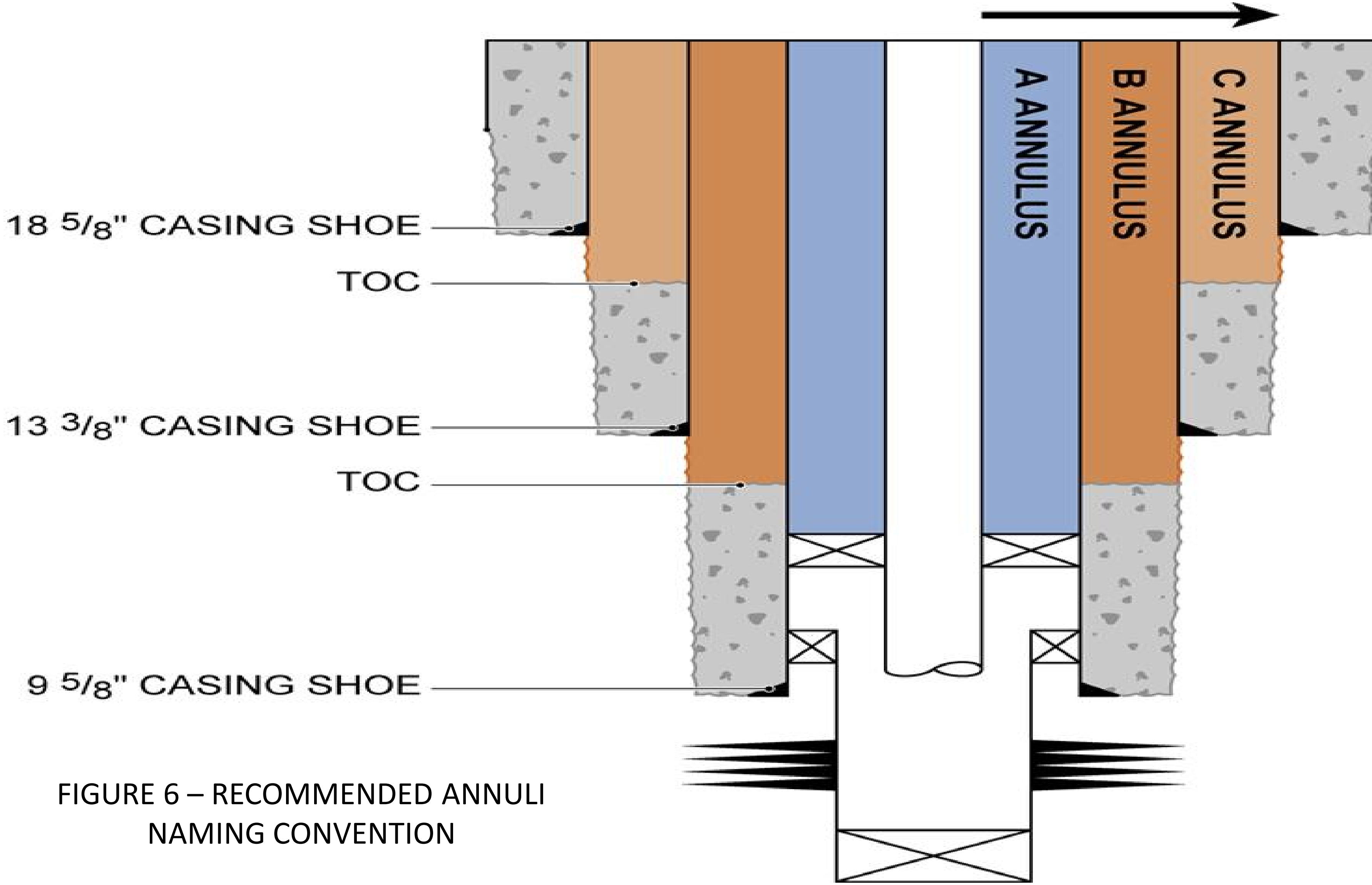

FIGURE 6 – RECOMMENDED ANNULI NAMING CONVENTION

Well Integrity for Hydraulically Fractured Wells

Recommendations for Maintaining Well Integrity of Hydraulically Fractured Wells:

- ✓ Recommend a minimum 2-barrier system for hydraulically fractured wells
- ✓ Monitor internal pressure on each barrier. If during hydraulic fracturing operations, annulus pressure > 500 psig – report to agency and take corrective action.
- ✓ Design casing for maximum burst and collapse loads for hydraulic fracturing. Test casing to 110% of maximum anticipated treatment pressure. If it fails, repair or use fracturing string (FS).
- ✓ If hydraulic fracturing is done through FS, the FS must be stung into a liner or run on a packer set within 100' TVD of cement top of production/ intermediate casing and tested to 110% of maximum treatment pressure less the annulus pressure between the FS and production/intermediate casing.
- ✓ Install pressure relief valve on treating lines so that max. treatment pressure is not exceeded.

Well Integrity for Hydraulically Fractured Wells

<u>Recommendations for Maintaining Well Integrity of Hydraulically Fractured Wells (Continued):</u>

- ✓ Keep surface casing valve open during hydraulic fracturing operation – so that casing flow or gas migration can be managed appropriately. The pressure in the annular space must not exceed the pressure rating of the lowest rated component in the FS.
- ✓ Operator's risk assessment and management (RA&M) plan must assess and mitigate the risks of inter-wellbore communication with an offset well within the fracture planning zone - FPZ (a ¼ mile radius of the wellbore trajectory and fracturing interval)
- ✓ Geological data on known/suspected faults and fractures that may transect the confining zones
- ✓ Identify all USDWs within a ¼ surface mile of the FPZ and address risks within the RA & M Plan. Suitable casing and cement design to prevent communication from the target HF zone into these aquifers.

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Questions ?

Thank you.