Hydrofracturing as a tool for increasing water well capacity

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Ground Water Science, LLC

Ground Water Science
Science and Planning for Earth’s Most Critical Resource
Acknowledgements

This presentation is based on:

*An Introduction to Water Well Hydrofracturing: A Form of Well Development and Cleaning*

By Allen Comeskey & Stuart Smith
to be published this year by the National Ground Water Association.
In 1989, Stuart Smith authored for NGWA: 
*Manual of Hydraulic Fracturing for Well Stimulation and Geologic Studies*

In 2015, NGWA approached Ground Water Science with the desire to update the manual as a second edition.

Include any new technologies and changes in the industry, such as regulatory environment.

NGWA is promoting the term *hydrofracturing* for water well applications, making a very sharp distinction from oil field *hydraulic fracturing*.
What is Hydraulic Fracturing?

Hydraulic fracturing, or “fracking,” involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.
Topics

- Brief History
- Basic Theory
- Three Approaches to Hydrofracturing
- Legal Environment
History

- Oilfield hydraulic fracturing started in the late 1940’s
- Hydraulic fracturing fluids and methods have evolved
  - 1940’s were gasoline based and thickened with napalm
  - 1950’s to 2000 introduced water-based, including gels and proppants, plus acid-based or foam-based.
  - 1970’s introduced deep high temperature operations that require millions of gallons of water
  - 2000 to present introduced “slickwater”, 99% water with friction reducers and surfactants
Water well hydrofracturing mentioned as early as 1960 for a limited number of applications.

Hank Baski speculates first domestic wells in the 1970’s.

Early hydrofracturing done with oilfield scale equipment that made it uneconomical compared to drilling a new well or other development techniques.
Water well hydrofracturing took off on its own trajectory from its oilfield roots some time in the 1960’s or 1970’s with some very significant differences:

- The geologic environments and resulting depths are different: deep sedimentary basins vs. 100’s to a couple of thousand feet
- The pressures are different: 20,000 to 100,000 p.s.i. vs. 2,000 to 6,000 p.s.i.
- The fluids are different: gasoline, friction reducers and surfactants vs. potable water, generally disinfected
- Additives are approved for water well construction and may be NSF approved
Elsworth (2013) stated that rocks fail in tension during hydraulic fracturing when the pore pressure exceeds the sum of the least principal stress and the tensile strength of the rock.

A simple expression may be:

\[ P > T_o + \sigma_3 \]

Where:

- \( P \) = pore pressure
- \( T_o \) = rock tensile strength
- \( \sigma_3 \) = least principal stress
Triaxial principal stresses in a formation
Resulting fracture orientation under failure

Adapted from Williamson and Woolley, 1980, p. 5
Orientation of the least principal is stress roughly depth related:

- At shallow depths it is vertical:
  - lithostatic pressure is relatively small
  - horizontal tectonic forces dominate the stress field

- At depth (> 9800 ft.) the least principal stress orients horizontally:
  - lithostatic pressure increases and eventually dominates the stress field
  - horizontal tectonic forces become a lesser component

Therefore with water wells, $\sigma_3$ will be a function of rock type and depth (height of rock column)
FRACTURE DEVELOPMENT AS FUNCTION OF WELLBORE ORIENTATION

From Charles Fairhurst and Intech Publishing
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Some common lithostatic pressures:

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Psi/ft. depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone 20 % porosity</td>
<td>0.98</td>
</tr>
<tr>
<td>Limestone</td>
<td>1.15</td>
</tr>
<tr>
<td>Dolomite</td>
<td>1.21</td>
</tr>
<tr>
<td>Shale</td>
<td>1.23</td>
</tr>
<tr>
<td>Granite</td>
<td>1.17</td>
</tr>
<tr>
<td>Basalt</td>
<td>1.30</td>
</tr>
<tr>
<td>Gneiss</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Adapted from Crane’s Petrophysical Handbook and EduMine
Tensile strength of the rock is a characteristic of the rock type and other factors:

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Tensile Strength (p.s.i.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>170 to 1,180</td>
</tr>
<tr>
<td>Limestone</td>
<td>229 to 579</td>
</tr>
<tr>
<td>Dolomite</td>
<td>440 to 640</td>
</tr>
<tr>
<td>Shale</td>
<td>30</td>
</tr>
<tr>
<td>Granite</td>
<td>1,726</td>
</tr>
<tr>
<td>Basalt</td>
<td>1,903 to 2,102</td>
</tr>
<tr>
<td>Gneiss</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Adapted from Goodman, 1989

Weathering, laminations, foliation, bedding planes, and solution cavities can influence tensile strength.
Three Applications

- Oilfield hydraulic fracturing creates increased porosity and permeability in the vicinity of a borehole.
- Water well hydrofracturing is predominantly a well cleaning method, but can range in scale and techniques applied.
  - **Jack and Flush**: Most common procedure. Jack open existing fractures and flush sediment to restore or enhance porosity and permeability.
  - **Jack and Prop**: Jack open existing fractures and pump in a proppant to enhance permeability.
  - **Fracture and Prop**: Classic oilfield procedure to fracture the rock and pump in proppants to create new porosity and permeability.
We hydrofracture bedrock wells with open hole completions.
Jack and Flush Technique:

Hank Baski describes a three-step well development method generally applied to crystalline rocks (Colorado, New England, Wisconsin):

1. High-pressure jacking open of fractures. Pressure adequate to overcome lithostatic pressure but not tensile strength
2. Pumping significant volumes of clear, disinfected water into the fractures
3. Release the pressure to allow backflow to surface with sediment entrained
Example:
West Chesterfield, MA, February 1988:
540 ft. well, 20 ft. 8-inch casing, SWL = 51 ft., 0.25 g.p.m.
Kyle Equipment unit with a single, triplex Cooper Industries pump, straddle packer
pressures up to 1150 p.s.i.

Return flow turbid

Results: increase to 6 g.p.m.
Jack and Prop Technique:

- Applied to both crystalline and sedimentary rocks, more frequently sedimentary rocks
- Pressure adequate to overcome lithostatic pressure but not tensile strength
- Jack open the fractures, displace blocks of rock, and inject sand proppant
- Pumping significant volumes of water, gel, drilling mud into the fractures, as vehicle for proppant
- No backflow to surface, may have to develop out excess sand and gel
Example:
Shell Valley Deep Well Project, WY, 1986:
Well 1 in Madison Ls. 2,421 ft. deep, Artesian flow at 176.5 g.p.m.
Equipment: Four Haliburton Pumper Trucks and one mixing truck
Single Packer, gelled water and sand pressures up to 2300 to 2800 p.s.i.
Excess sand was developed out
Results: increase flow to 367 g.p.m.
Fracture and Prop Technique:

- Applied more frequently to sedimentary rocks
- Pressure adequate to overcome both lithostatic pressure and tensile strength
- Exploit bedding planes, solution cavities, which lowers tensile strength further
- Create and propagate fractures and inject sand proppant
- Pumping significant volumes of water, gel, drilling mud into the fractures, as vehicle for proppant
- Requires oilfield scale equipment to provide pressures and fluid volumes
- No backflow to surface, may have to develop out excess sand and gel
Example:
City of Gillette, WY, 1992:

3000 ft. well in Madison Ls.,
2300 ft. casing,
Producing zone lots of solution cavities

Halliburton contracted to hydrofracture the well with a single packer, clear water and sand proppants

Large scale equipment to maintain pressures and fluid volumes

pressures up to 1141 p.s.i.

Results: Specific capacity increased from 2.9 g.p.m./ft. at 640 g.p.m. to 31 g.p.m./ft. at 600 g.p.m.
Legal Environment

- Contractors will need to be familiar with the specific regulations in the states in which they work. Twenty states at least mention hydrofracturing in their regulations (Water Systems Council, 2010).
- Water Systems Council *Special Report No. 6* summarizes state-by-state water well and hydrofracturing regulations.
- A searchable database of state water well regulations can be found at watersystemscouncil.org.
Richardson (2011) summarized the various activities covered by state regulations:

- **Contractor certification or license** – license to operate or certification of expertise, or both
- **Permit requirement** – local or state permit prior to fracturing
- **Notices** – either to nearby land owners, or to the state when public water supply wells involved
- **Reporting** – specific to fracturing activities or as part of well construction
- **Follow-up testing** - provide tests or estimates of final yield
- **Fracturing water quality or disinfection** – Potable quality or disinfected / chlorinated, prior approval of fluid, or safe for groundwater and environment
- **Packer placement** – generally prohibit injecting into casing, deal with packer spacing or placement below casing
- **Isolation (setbacks)** - from contaminant sources or other wells
- **Geologic settings limitations** – Limited to consolidated formations, or specified rock type