Hydraulic Fracturing
Fracture’s Mechanics
Reservoir’s Type

- Conventional

- Non Conventional
  • Shale Gas
  • Coalbed Methane (CBM)
  • Tight Sands
  • Heavy Oil
- Non Conventional

• Shale Gas

- Low porosity and permeability;
- Well stratified
- High reservoir´s volume
1. Reservoir’s Type

- Non Conventional

- Coalbed Methane (CBM)

- Coal’s High specific Area leads to great CH4 storage
1. Reservoir’s Type

- Non Conventional
  • Tight Sands

- Permeability lower than 0.1 mD
- Absence of connectivity
- Geological uncertainty
1. Reservoir’s Type

- Non Conventional

• Heavy Oil

  - API between 10° and 22.3°
  - High viscosity
2. Directional well

Horizontal Drilling

• Causes

• Consequences
3. Well’s Stimulation

Well’s Stimulation

- Matrix Acidification
- Acid Fracturing
- Hydraulic Fracturing
3. Well’s Stimulation

• Acid Fracturing
• Matrix Acidification

Higher conductivity, due to the formation of residual channels associated with a non-homogeneous acid’s diffusion.
Hydraulic Fracturing

- History
- Hydraulic fracturing operation
- Fracture’s Fluid (proppant)
- Fracture’s Mechanics
- Ambiental Integration and problems
### History

#### Evolution of Hydraulic Fracturing

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Stage</td>
<td>Rudimentary technique of stimulation</td>
</tr>
<tr>
<td>1947</td>
<td></td>
</tr>
<tr>
<td>1950's</td>
<td>First Mathematical Models</td>
</tr>
<tr>
<td>1960's</td>
<td>Advances in equipments, fluids and monitoring processes</td>
</tr>
<tr>
<td>1970's</td>
<td>Tight gas e massive fracs</td>
</tr>
<tr>
<td>1990's</td>
<td>New scenarios for the application of the technique: plays with high permeability and introduction to “fracpacking”</td>
</tr>
</tbody>
</table>

### Well’s Stimulation

**Table:**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Shale gas (trillion cubic feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>1,115</td>
</tr>
<tr>
<td>2</td>
<td>Argentina</td>
<td>802</td>
</tr>
<tr>
<td>3</td>
<td>Algeria</td>
<td>707</td>
</tr>
<tr>
<td>4</td>
<td>U.S.</td>
<td>665 (1,161)</td>
</tr>
<tr>
<td>5</td>
<td>Canada</td>
<td>573</td>
</tr>
<tr>
<td>6</td>
<td>Mexico</td>
<td>545</td>
</tr>
<tr>
<td>7</td>
<td>Australia</td>
<td>437</td>
</tr>
<tr>
<td>8</td>
<td>South Africa</td>
<td>390</td>
</tr>
<tr>
<td>9</td>
<td>Russia</td>
<td>285</td>
</tr>
<tr>
<td>10</td>
<td>Brazil</td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>World Total</td>
<td>7,299 (7,795)</td>
</tr>
</tbody>
</table>

**Fig. 4—**Estimated global distribution of fracturing equipment, including land fracturing spreads and offshore vessels.
3. Well’s Stimulation

- Hydraulic Fracturing Operation

- Rock’s rupture by negative stresses

- Fluid pumped to 8,000 psi is enough to prefurate until 914,4 meters distance

- Under pressure, the fractures nearest the well can measure between 3,175 mm and 6,35 mm
Hydraulic Fracturing Operation

Enormous water consumption; 50% recycled!
Hydraulic Fracturing Operation

Enormous water consumption; 50% recycled!

Logistic’s management is essential!
• Proppant

3. Well’s Stimulation

- Proppant

Água e proppant: ~98%

Outros: ~2%
- Ácido
- Agente antibacteriada
- Coagulador
- Estabilizador de Argila
- Inibidor de corrosão
- Crosslinker
- Redutor de Fricção
- Gelificante
- Controlador de Ferro
- Agente de ajuste de pH
- Inibidor de incrustação
- Surfactante

Injeção de fluido de fraturamento

Fraturas existentes

Direção das forças hidrodinâmicas

Injeção de fluido de fraturamento

Direção do fluido

Injeção de fluido e de proppant

Fluido de fraturamento

Transporte de proppant

Limpzea/produção do poço

Extracão de fluido/óleo

Fluido aprisionado

Propante
• Fracture’s Mechanics

- Anisotropic
- Non homogeneous
3. Well’s Stimulation

- Fracture’s Mechanics

\[ t_{TOT} \gg \left( \frac{\mu Q^3 E'}{K^{18}} \right)^{1/2} \]

Resistance

\[ t_{TOT} \ll \left( \frac{\mu Q^3 E'}{K^{18}} \right)^{1/2} \]

Viscosity

- PKN (Perkins & Kern)
- GDK (Geertsma & de Klerk)

Area of largest flow resistance

Approximately elliptical shape of fracture

Gain of well production rate vs. propped fracture conductivity

Permeability vs. closure stress (darcy)

Characteristics of a 12/20 ISP, intermediate strength proppant

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May 8th 2014
3. Well’s Stimulation

* Fracture’s Mechanics (Fluid Propagation)

- Lagrangian approach:
  - Fracture Volume
  - Fluids Loss

\[ Q = \partial E / \partial q + \partial D / \partial q \]

FEM 2D Vs 3D (for spatial variation)

* Variation in time domain by FDM
3. Well’s Stimulation

• Fracture’s Mechanics (Fluid Flow)

Fluid Flow analysis
(Darcy’s Law)

\[ v_{FT} = \frac{q}{A} = k_{TF} \frac{2a_i}{d} I \]

*Quasi-static conditions
*Quasi-incompressible Fluids

Forchheimer’s equation
turbulence coefficient

**Fig. 2:** Relationship between plastic strain and permeability

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_{FT} )</td>
<td>flow velocity</td>
</tr>
<tr>
<td>( K )</td>
<td>anisotropic permeability tensor of jointed rock mass</td>
</tr>
<tr>
<td>( 2a_i )</td>
<td>joint thickness / joint opening</td>
</tr>
<tr>
<td>( A )</td>
<td>cross section</td>
</tr>
<tr>
<td>( d )</td>
<td>joint frequency</td>
</tr>
</tbody>
</table>

respectively transformed into global coordinate system \( \{v_{FT}\} = K \{I\} \)
- **Fracture’s Mechanics (Resistance)**

\[
\sigma = D_{RM} (\varepsilon^{\text{tot}} - \varepsilon^{pl})
\]

\[
\{\varepsilon\}^{\text{tot}} = \{\varepsilon\}^{\text{el}} + \{\varepsilon\}^{pl}
\]

\[
d\varepsilon^{pl} = \lambda \frac{\partial Q}{\partial \sigma}
\]

\[F(\{\sigma\}, \kappa) \leq 0\]

- **3. Well’s Stimulation**

\{\sigma\} - stress vector

\(\kappa\) - hardening or softening

\(\lambda\) - plastic multiplier

\(Q\) - plastic potential
3. Well’s Stimulation

- Fracture’s Mechanics

\[
\left\{ \frac{\partial F_n}{\partial \sigma} \right\}^T \begin{bmatrix} D \end{bmatrix} \sum_{j=1}^{\text{Set of active } \text{YC}} \left\{ \frac{\partial F_n}{\partial \sigma} \right\}^T \begin{bmatrix} D \frac{\partial Q_j}{\partial \sigma} - \frac{\partial F_n}{\partial \kappa_n} \frac{\partial \kappa_n}{\partial \lambda_j} \end{bmatrix} d\lambda_j
\]

*In global coordinates

* At least 2.88 minutes discretization!

**Fig. 5:** Stimulated rock body after 193 minutes of pressuring (blue: stimulated rock mass from simulation, red: seismic mapping measurements)

Optimization
3. Well’s Stimulation
4. Ambiental concerns

- Ambiental integration and problems
  - Aquifer contamination
  - BlowOut Risk
  - Seismic Risk
4. Ambiental concerns

- Ambiental integration and problems
4. Ambiental concerns

- Ambiental integration and problems
• Ambiental integration and problems
4. Ambiental concerns

- Ambiental integration and problems
6. Conclusion

- Hydraulic fracturing can provide to most countries an attractive combustible’s alternative

- It’s believed the innovation and new practises at the industry can help to manage the risks with the application of the technique: Bad construction, blowouts, Aquifer contamination, among others

- There are many constitutive model, focused in different parameters and properties, but the advanced of the FEM modelling can bring the feeling of complete comprehension of the theme by all people in general

“Wall Street’s Brightest Minds Reveal Their Best Investment Ideas For The Next Decade”

8. International pressure pumping

"The one investment I think I'd make to hold over the next 10 years would be in oil services, particularly focusing on international pressure pumping. While crude oil continues to ratchet upwards in price and get more and more expensive to find, natural gas through hydraulic fracturing seems to get easier with the boundaries for ever wider-scale production halted by the factionalism and arbitrary hypocrisy of government controls, particularly in the shale rich areas of South America. Those barriers must fall, given the price differential that continues to expand between crude and gas; and the international services group will be the most likely long-term benefactors — think Schlumberger (SLB) and Baker-Hughes (BHI)."

—Dan Dicker, president of MercBloc
11. WORKMAN, SETH JORDAN. (2013). “Integrating Depositional Facies and Sequence Stratigraphy in Characterizing Unconventional Reservoirs: Eagle Ford Shale, South Texas”.
18. Hydraulic Fracturing; The fuss, the facts, the future
20. Magnus Wangen, “Modelling HF on a reservoir scale 2D”
21. Oilfield Review ; “Rocks Matter:Ground truth in Geomechanics”
22. Johannes Will; “Simulation of HF of jointed rock”

5. http://www.youtube.com/watch?v=WP5wSfD0fk4
6. http://www.youtube.com/watch?v=TGC0K9tPPTo

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May 8th 2014