Comparison of Hydraulic Stimulation Methods of Coals and Carbonaceous Shales in the Cherokee Basin*

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Abstract

The Cherokee Basin in southeastern Kansas and northeastern Oklahoma produces gas from Cherokee Formation coals and carbonaceous mudstones. From 1990 to 2009, these coals and carbonaceous mudstones were exploited by several operators and peaked at over 1,000 wells per year. Activity ceased with the collapse of gas prices in 2008 to 2009. Several different hydraulic stimulation methods were used as well as types of stimulation design to specifically to stimulate individual or multiple seams. The majority of the wells in the basin have over eight years of production history that allows for analysis of the various stimulation methods. Comparison of individual zone completion versus multiple seam completion was done. This study suggests that that cross-link gel was as effective as slick water. Another conclusion is that stimulating individual zones was significantly more effective than stimulating several zones with the same fracture stimulation. In addition, certain Operators were more effective at maximizing gas production. Several other trends were also identified that will be discussed. While gas prices remain low this analysis allows identification of re-stimulation candidates, behind pipe resources and potential other areas that remain to be exploited.

Reference Cited

Comparison of hydraulic stimulation methods of coals and carbonaceous shales in the Cherokee Basin

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Abstract

The Cherokee Basin produces gas from the Desmoinesian and Atoka age Cherokee Formation coals and carbonaceous mudstones at less than 2,000 feet. From 1990 to 2009 the Cherokee underwent an active exploitation of the coals and carbonaceous shales in the Cherokee Basin peaking at over 1,000 wells per year. Exploitation ceased with the collapse of gas prices in 2008 to 2009. Several different hydraulic stimulation methods were used as well as techniques designed to specifically to stimulate individual or multiple seams. The majority of the wells have over ten years of production and allows for analysis of the effectiveness of the various stimulation methods, individual versus multiple seam and by Operator. The result indicates that cross-link gel was as effective as slick water, stimulating individual zones was significantly more effective than stimulating several zones with the same fracture stimulation. Production from wells where two or more zones were fractured stimulated had very steep decline rates whereas those wells where each stimulation stimulated a specific coal or carbonaceous shale were more productive. Several other trends were also identified that will be discussed. While gas prices remain low this analysis allows a re-evaluation of where opportunities are within the existing wellbores.
Location of Cherokee Basin

- Shallow intracratonic basin;
- Potential 6 TCF in gas according to the USGS;
- Oil production from 150 to 3,800 feet;
- Gas production from 150 to 2,400 feet.
Gas Production to 2012

The Cherokee Basin was first exploited for unconventional reservoirs in the 1920s from Tulsa to Kansas City;

99% of the wells are vertical;

Extensive gas gathering and pipeline system.
Stratigraphic Column

- Carbonaceous Shale
- Excello
- Mulky
- Weir-Pittsburg
- Rowe
- Riverton
- Bartlesville Sandstone - main oil pay zone
Coal and Carbonaceous Mudstones

Coal reservoir characteristics
• Thin 1 to 2 feet thick;
• High Volatile B to Medium Volatile;
• Poor vitrinite content: 65% to 85%;
• Friable;
• Poorly cleated;
• Bright to dull;
• Laminated;
• High Inertinite and Fusinite;
• High Ash;
• High sulfur;
• No de-watering.

Carbonaceous Mudstones reservoir characteristics
• Thin 1 to 10 feet thick;
• $R_o$ 0.45 to 0.76;
• Marine to terrestrial;
• Quartz and carbonate <50% except Excello Shale;
• Laminated;
• No de-watering.

Basin characteristics
• Underpressured, 0.34 gradient;
• Depth of burial < 6,000 feet;
• Maturation of coals and carbonaceous mudstones related to thin Pre-Pennsylvanian Paleozoic cover;
• Migrating low temperature hydrothermal fluids.
Map of the Riverton Interval
Cumulative Production up to 2011

Gas Production by township for 2nd, 3rd, and 4th years.

Gas production by well for 2nd, 3rd, and 4th years.

Tedesco, 2014
Number of Wells Per Township
Total Gas Production in MCF per Well
Pay Zone By Well
Location of Study Areas

Blue Dots are CBM wells
Average and median production for the basin based from 1990 to 2011

Re-fracture stimulation or new zones open

Average

Median
Production Curves (Logarithmic) by year for individual operators
Jefferson-Sycamore Study Area

Operators
- Bluejay Operating
- Stroud Oil Properties
- Great Eastern
- Jones Gas
- Dart Operating
- Layne Operating
Decline Curve and Pay Distribution for the Jefferson-Sycamore Study Area
Structure on top of the Mississippian for the Jefferson-Sycamore Study Area
Structure on top of the Cherokee Group for the Jefferson-Sycamore Study Area
Isopach of the Cherokee Group for the Jefferson-Sycamore Study Area
Isopach of the Riverton Coal for the Jefferson-Sycamore Study Area

Red arrows and lines represent areas of water flow and no coal development. In some cases they could be areas that were conducive to swamp development.
Isopach of the Weir-Pittsburg Coal for the Jefferson-Sycamore Study Area

Red arrows and lines represent areas of water flow and no coal development. In some cases they could be areas that were conducive to swamp development.

Note the lack of similarities between where the Riverton and Weir-Pittsburg coals developed.
Number of fracture stimulations and Gas Production for the Jefferson Sycamore Area
Fracture Stimulation in the Jefferson-Sycamore Area

<table>
<thead>
<tr>
<th>Operator</th>
<th>Bluejay Operating</th>
<th>Dart Cherokee</th>
<th>Great Eastern</th>
<th>Jones Gas Company</th>
<th>Layne Operating</th>
<th>Stroud Oil Properties</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Wells</td>
<td>20</td>
<td>302</td>
<td>42</td>
<td>33</td>
<td>166</td>
<td>20</td>
<td>610</td>
</tr>
<tr>
<td>COMPONENT</td>
<td>Sand in pounds</td>
<td>27,500</td>
<td>14,640</td>
<td>15,000</td>
<td>19,600</td>
<td>16,800</td>
<td>28,000</td>
</tr>
<tr>
<td>Sand per foot</td>
<td>1,931</td>
<td>1,570</td>
<td>2,663</td>
<td>2,321</td>
<td>962</td>
<td>7,288</td>
<td>1,703</td>
</tr>
<tr>
<td>Sand in pounds per foot</td>
<td>2,000</td>
<td>1,503</td>
<td>1,916</td>
<td>2,000</td>
<td>885</td>
<td>6,750</td>
<td>1,430</td>
</tr>
<tr>
<td>Fluid in barrels</td>
<td>1,205</td>
<td>639</td>
<td>548</td>
<td>1,394</td>
<td>473</td>
<td>1,175</td>
<td></td>
</tr>
<tr>
<td>Fluid per foot in barrels</td>
<td>123</td>
<td>85</td>
<td>58</td>
<td>74</td>
<td>158</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>Hydrochloric acid (HCL) in gallons</td>
<td>1,300</td>
<td>413</td>
<td>500</td>
<td>2,190</td>
<td>350</td>
<td>1,500</td>
<td></td>
</tr>
<tr>
<td>Total pay in feet</td>
<td>14</td>
<td>10</td>
<td>6</td>
<td>9</td>
<td>19</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>No. of fracture stimulations</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>No. of zones open</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Cumulative production in MCF</td>
<td>25,482</td>
<td>61,229</td>
<td>96,068</td>
<td>70,205</td>
<td>52,915</td>
<td>192,122</td>
<td>58,848</td>
</tr>
<tr>
<td>Cumulative production 2\textsuperscript{nd}, 3\textsuperscript{rd}, and 4\textsuperscript{th} year</td>
<td>15,800</td>
<td>33,322</td>
<td>30,246</td>
<td>32,774</td>
<td>31,817</td>
<td>51,512</td>
<td>30,999</td>
</tr>
<tr>
<td>Median daily production 2\textsuperscript{nd}, 3\textsuperscript{rd}, and 4\textsuperscript{th} year</td>
<td>14</td>
<td>28</td>
<td>28</td>
<td>30</td>
<td>29</td>
<td>47</td>
<td>28</td>
</tr>
</tbody>
</table>

Fracture Stimulation
- Stroud - single fracture stimulation and cross-link gel
- Layne - multiple zone per each fracture stimulation
- Dart - fracture stimulate each individual zone
Total Pay Versus Gas Production in the Jefferson-Sycamore Area

Number of fracture stimulations versus gas production in the 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} year

Fracture stimulating two to four zones is detrimental to gas production when compared to one stimulation.

Total feet in pay versus gas production in the 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} year
Two Wells: Single versus Multiple in the Jefferson-Sycamore Study Area

An example of how a multiple zone completion faired poorly when compared to a single zone completion.
Combination of the different pays and their associated production in the Jefferson-Sycamore Study Area

<table>
<thead>
<tr>
<th>Component</th>
<th>Sand in pounds</th>
<th>Sand in pounds per foot</th>
<th>Fluid in barrels</th>
<th>Fluid per foot in barrels</th>
<th>HCl in gallons</th>
<th>Average total pay in feet</th>
<th>No. of fracture stimulations</th>
<th>No. of zones open</th>
<th>Cumulative production in MCF</th>
<th>Cumulative production 2nd, 3rd, and 4th year in MCF</th>
<th>Average daily production 2nd, 3rd, and 4th year in MCF</th>
<th>No. of wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Riverton coal</td>
<td>7,531</td>
<td>15,123</td>
<td>16,402</td>
<td>12,400</td>
<td>15,810</td>
<td>7,500</td>
<td>14,970</td>
<td>15,100</td>
<td>12,400</td>
<td>15,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Riverton coal</td>
<td>1,595</td>
<td>582</td>
<td>1,421</td>
<td>3,100</td>
<td>556</td>
<td>1,442</td>
<td>1,422</td>
<td>2,339</td>
<td>1,472</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Rowe-Drywood coals</td>
<td>195</td>
<td>1,769</td>
<td>1,325</td>
<td>307</td>
<td>1,261</td>
<td>413</td>
<td>662</td>
<td>945</td>
<td>1,215</td>
<td>389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Weir-Pittsburg coal</td>
<td>78</td>
<td>68</td>
<td>95</td>
<td>102</td>
<td>98</td>
<td>138</td>
<td>49</td>
<td>95</td>
<td>96</td>
<td>91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Riverton coal</td>
<td>300</td>
<td>74,298</td>
<td>1,608</td>
<td>1,500</td>
<td>2,400</td>
<td>1,100</td>
<td>1,500</td>
<td>350</td>
<td>1,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Rowe-Drywood coals</td>
<td>13</td>
<td>78</td>
<td>68</td>
<td>95</td>
<td>102</td>
<td>98</td>
<td>138</td>
<td>49</td>
<td>95</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Weir-Pittsburg coal</td>
<td>131</td>
<td>68</td>
<td>95</td>
<td>102</td>
<td>98</td>
<td>138</td>
<td>49</td>
<td>95</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Excello-Little Osage</td>
<td>133</td>
<td>68</td>
<td>95</td>
<td>102</td>
<td>98</td>
<td>138</td>
<td>49</td>
<td>95</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. Marmaton completions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of fracture stimulations versus gas production in the 2nd, 3rd and 4th year
Productive Areas versus location by Operator in the Jefferson-Sycamore Study Area

Cumulative gas production up to 2011.

Red is best and purple is worst.

Location of the various operator in the study area (color coded wells with the best productive areas overlain on the map)
High Productive Areas in relation to structure and thickness in the Jefferson-Sycamore Study Area

Mississippian Structure

Cherokee Group Structure

Cherokee Group Isopach
High Productive areas in relation to coal seam thickness in the Jefferson-Sycamore Study Area

Riverton

Weir-Pittsburg
# Economics of a Coal-Bed Methane for the Jefferson-Sycamore Study Area

<table>
<thead>
<tr>
<th>Operator</th>
<th>No. of Fractures</th>
<th>Type of Stimulation</th>
<th>Costs Per Well</th>
<th>Median MCF</th>
<th>Return of Capital*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layne</td>
<td>3 to 5</td>
<td>Slick water</td>
<td>$140,000</td>
<td>52,915</td>
<td>1.1</td>
</tr>
<tr>
<td>Great Eastern</td>
<td>1 to 2</td>
<td>X-link and slick water</td>
<td>$120,000</td>
<td>96,068</td>
<td>1.6</td>
</tr>
<tr>
<td>Dart</td>
<td>3 to 7</td>
<td>slick water</td>
<td>$150,000</td>
<td>61,229</td>
<td>1.2</td>
</tr>
<tr>
<td>Jones</td>
<td>1 to 2</td>
<td>slick water</td>
<td>$120,000</td>
<td>70,205</td>
<td>1.4</td>
</tr>
<tr>
<td>Stroud Oil Properties</td>
<td>1 to 2</td>
<td>x-link</td>
<td>$110,000</td>
<td>192,122</td>
<td>2.1</td>
</tr>
</tbody>
</table>

* Based on $6 gas, 80% NRI, $1.50 transportation costs
Comparison from all five study areas

Thayer and the Jefferson-Sycamore study areas have the best production of the five study areas.

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Jefferson-Sycamore</th>
<th>Thayer</th>
<th>Chanute</th>
<th>Bourbon</th>
<th>Mound Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand (in thousands of pounds)</td>
<td>15</td>
<td>17</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Fluid (in barrels)</td>
<td>1,175</td>
<td>1,375</td>
<td>470</td>
<td>876</td>
<td>1,156</td>
</tr>
<tr>
<td>Total pay (in feet)</td>
<td>11</td>
<td>17</td>
<td>4</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Cross-linked gel (in MMCF)</td>
<td>31</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>76</td>
</tr>
<tr>
<td>Slick water (in MMCF)</td>
<td>31</td>
<td>66</td>
<td>21</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Nitrogen (in MMCF)</td>
<td>67</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>One stimulation (in MMCF)</td>
<td>87</td>
<td>65</td>
<td>21</td>
<td>9</td>
<td>40</td>
</tr>
<tr>
<td>Two stimulations (in MMCF)</td>
<td>51</td>
<td>65</td>
<td>21</td>
<td>8</td>
<td>29</td>
</tr>
<tr>
<td>Three stimulations (in MMCF)</td>
<td>49</td>
<td>44</td>
<td>22</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Four stimulations (in MMCF)</td>
<td>49</td>
<td>133</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Five stimulations (in MMCF)</td>
<td>66</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Six stimulations (in MMCF)</td>
<td>60</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Seven stimulations (in MMCF)</td>
<td>112</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Median production (in MMCF)</td>
<td>59</td>
<td>66</td>
<td>21</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Structure necessary</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Primary producing coal</td>
<td>Riverton and Weir-Pittsburg</td>
<td>Riverton and Rowe</td>
<td>Riverton</td>
<td>Riverton</td>
<td>Weir-Pittsburg</td>
</tr>
<tr>
<td>Thinning or thickening of individual intervals or coals</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Isopach thinning of the Pre-Pennsylvanian Paleozoic rocks</td>
<td>Yes</td>
<td>Yes</td>
<td>Periphery</td>
<td>No</td>
<td>Periphery</td>
</tr>
</tbody>
</table>
Comparison of gas production versus Operators and number of fracture stimulations in all five study areas

Median gas production for operators with more then ten wells for the 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} years versus number of fracture stimulations

Median gas production for operators with more then ten wells for the 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} years versus number of fracture stimulations
Summary

- Gas production is not related to any perceived thickening of coal or carbonaceous shale or structure;
- One fracture stimulation is more economic than two, three or four fracture stimulations;
- X-link gel was generally superior than slick water;
- Nitrogen was significantly better but the number of wells where it was used is small and there is a significant increase in costs;
- Overall based on economics the Cherokee Basin coal bed methane play is a marginally to uneconomic gas resources that is very dependent upon price.
Thank you for coming

The End