Selection and Treatment of Stripper Gas Wells for Protection Enhancement in the Mid-Continent

Presented by:
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Project Genesis

• In 1996, GRI (now GTI) began investigating potential for natural gas production enhancement via restimulation. Initial findings were:
  – Significant potential
    • >5 tcf incremental reserves in 5 years
  – Low reserve costs when successful
    • $0.10 - $0.20/Mcf
  – Critical success factors
    • Candidate selection (85/15 rule)
    • Problem diagnosis
    • Treatment strategy

• Major obstacles are:
  – Industry’s (understandable) reluctance to restimulate “good” wells, which frequently are the best candidates
  – Lack of “tools” or methods to cost-efficiently identify candidates and diagnose well performance problems
Subsequent Work

• GRI initiated a subsequent R&D program in 1998 with four primary objectives:
  ▪ Develop cost-effective, reliable methodologies to identify wells with high restimulation potential in tight sands.
  ▪ Identify various mechanisms leading to well underperformance.
  ▪ Develop new restimulation techniques tailored to selected causes of well underperformance.
  ▪ Demonstrate that with improved candidate recognition, problem diagnosis and restimulation methods, restimulation can be a substantial source of low-cost natural gas.
Candidate Selection Concept

- **Screening**
  - Rapid
  - Not engineering based
  - Statistical, AI approaches

- **Evaluation**
  - Engineering-based
  - Problem diagnosis, treatment selection
  - Forecasting, economic ranking

Sample Outcome
- Well No.
- Incremental Reserves
- Restimulation Economics

100 Wells (total population) → 50 Wells (potential candidates) → 15 Wells (high potential) → Candidate Verification

100 Wells
(total population)

50 Wells
(potential candidates)

15 Wells
(high potential)

Candidate Verification
Location of Restimulation Project Test Sites

Green River Basin
- Big Piney/LaBarge Producing Complex
- Frontier Formation
- Enron Oil & Gas (now EOG Resources)

Piceance Basin
- Grand Valley/Parachute/Rulison Fields
- Williams Fork Formation
- Barrett Resources (now Williams)

East Texas Basin
- Carthage Field
- Cotton Valley Sandstone
- Union Pacific Resources (now Anadarko)
Track Record of Success

- 9 wells restimulated
  - Green River Basin – 4
  - Piceance Basin – 2
  - East Texas Basin – 3
- 7 production improvements, 1 no change, 1 slight decline
- 6 “economic” successes
- Added 2.9 Bcf of reserves at a total reserve cost of $0.26/Mcf (costs include “failed” restimulations).
- Value of reserves gained by Operators more than offset cost of “R&D” project.

DOE Stripper Well Program

- Initiated in 2000.
- Objective of sustaining/improving production and reserves from stripper gas wells.
- Technologies developed under earlier GTI sponsorship can be modified for stripper well application.
## U.S. Stripper Gas Distribution

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Number of Stripper Gas Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>West Virginia</td>
<td>35,594</td>
</tr>
<tr>
<td>2</td>
<td>Ohio</td>
<td>33,430</td>
</tr>
<tr>
<td>3</td>
<td>Texas</td>
<td>27,368</td>
</tr>
<tr>
<td>4</td>
<td>Pennsylvania</td>
<td>26,000*</td>
</tr>
<tr>
<td>5</td>
<td>Kentucky</td>
<td>14,126</td>
</tr>
</tbody>
</table>

* Estimated

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Production from Stripper Wells (Mcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Texas</td>
<td>221,513,637</td>
</tr>
<tr>
<td>2</td>
<td>West Virginia</td>
<td>198,500,000</td>
</tr>
<tr>
<td>3</td>
<td>Oklahoma</td>
<td>114,668,483</td>
</tr>
<tr>
<td>4</td>
<td>Pennsylvania</td>
<td>100,000,000*</td>
</tr>
<tr>
<td>5</td>
<td>Ohio</td>
<td>79,333,000</td>
</tr>
</tbody>
</table>

*Estimated
Presentation Outline

Background

Project Description

Prior Work

Technology

Current Field Work

Application Guidelines

Future Work
Strategic Objective

• To develop an easy-to-use, low-cost analytic methodology to identify untapped production enhancement potential in stripper gas wells.
Tactical Objectives

• Develop a Candidate Screening & Selection Methodology
• Perform Field Demonstrations of its Application
• Disseminate Results to Industry
Project Scope

- Geographic
  - Mid-Continent
- Applications ("existing" production)
  - Restimulation
  - Production Practices (downhole and surface)
Virtual Intelligence

• Artificial Neural Networks (well performance model)
  - Statistical analogy
  - Pattern recognition
  - No “engineering” or “interpretive” bias

• Genetic Algorithms (best practices, problem identification)
  - Optimized optimization
Type-Curves

• Current Features
  ➢ Two-layer
  ➢ Variable Compressibility
  ➢ Fractured/Unfractured

• New Features
  ➢ Secondary Curves (e.g., cumulative production)
  ➢ Batch Processing

• Utility
  ➢ Differentiate depletion, low permeability, damage, production practices
  ➢ Quantify upside potential
Candidate Selection Approach

- Combine results of VI and TC analyses to identify candidates.
- Develop a screening/selection routine.
Perform Field Demonstrations

Perform Integrated Field Demonstrations

• Two Sites (+/- 100 wells each)
  > Tight Gas Formation
  > High-Permeability/Low-Pressure Formation

• Activities
  > Collect Data
  > Perform VI, Type-Curve Analyses
  > Select Candidates, Remediation Methods
  > Perform Treatments/Workovers (1-3 per site)
Current Status

• Performing candidate selection analytics at first test site.
• Seeking second test site.
Candidate Selection Methods

- **Statistics**
  - Public/Easily-Obtained Data
  - Production Statistics

- **Pattern Recognition**
  - Geologic, Log, Drilling, Completion, Stimulation, Workover Data
  - Minimum Data Interpretation
  - Virtual Intelligence (Artificial Neural Networks, Genetic Algorithms, Fuzzy Logic)

- **Engineering**
  - Engineering-Based Approach (Type-Curves, etc.)
  - Ranked by Incremental Production Potential
Data and Interpretation Requirements

- Low Data Requirements
- High Data Requirements
- Low Interpretation Requirements
- High Interpretation Requirements

- Time, Cost Increases
- Pattern Recognition
- Engineering
Coincidence Of “Top 50” Candidate Selections, Green River Basin

Statistics

Pattern Recognition

26 wells

9

9

6

5

30 wells

30 wells

Note: Top Candidates from each process do not necessarily coincide with top candidates from other processes.
Benchtop Study

- Create a hypothetical (simulated) field where all reservoir/completion properties are known, and restimulation potential can be readily computed.
- Independently select restimulation candidates with each technique and compare the selections with the known “answer.”
- Make the exercise as realistic as possible.
## Comparison of Restimulation Candidate Selection Methods

<table>
<thead>
<tr>
<th>Approach</th>
<th>Incremental (Bcf)</th>
<th>Efficiency (Top 18 Wells)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>4.566</td>
<td>100%</td>
</tr>
<tr>
<td>Best Pre-Restim Rate</td>
<td>3.896</td>
<td>85.3%</td>
</tr>
<tr>
<td>Virtual Intelligence</td>
<td>3.807</td>
<td>83.4%</td>
</tr>
<tr>
<td>Type Curves</td>
<td>3.421</td>
<td>74.9%</td>
</tr>
<tr>
<td>Best 10-Year Cum.</td>
<td>3.272</td>
<td>71.7%</td>
</tr>
<tr>
<td>Random</td>
<td>2.150</td>
<td>47.1%</td>
</tr>
<tr>
<td>Production Statistics</td>
<td>1.949</td>
<td>42.7%</td>
</tr>
<tr>
<td>Worst 10-Year Cum</td>
<td>0.775</td>
<td>17.0%</td>
</tr>
<tr>
<td>Worst Pre-Restim Rate</td>
<td>0.735</td>
<td>16.1%</td>
</tr>
</tbody>
</table>

Ultimate Conclusions

• Better wells make better restimulation candidates.

• Each candidate selection methodology may have specific applicability:
  - Statistics: Reservoir/operating practices broadly uniform.
  - Pattern Recognition: High degree of reservoir heterogeneity & completion/stimulation variation.
  - Engineering: High quality reservoir and production data.
Relevance to Stripper Wells

• Focusing on “best” stripper wells counter-intuitive.

• Adopt an integrated VI & TC approach with a screening criteria to tie them together.
  
  ➢ Weighting of one approach vs. the other can be a site-specific variable.
Virtual Intelligence

• Uni-variate analysis
• Multi-variate analysis
• Pattern recognition (artificial neural network).
Illustration of ANN Structure
# Example Virtual Intelligence Methodology

<table>
<thead>
<tr>
<th>ARTIFICIAL NEURAL NET WORK</th>
<th>GENETIC ALGORITHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space: X, Y, Z</td>
<td>• Total Proppant Volume</td>
</tr>
<tr>
<td>Time: Completion Date</td>
<td>• Total Fluid Volume</td>
</tr>
<tr>
<td>Completion: No. Perf. Intervals</td>
<td>• Fluid Type</td>
</tr>
<tr>
<td>Total Net Thickness</td>
<td></td>
</tr>
<tr>
<td>No. Fracs</td>
<td>FUZZY LOGIC</td>
</tr>
<tr>
<td>Total Proppant Volume</td>
<td>• GA Incremental</td>
</tr>
<tr>
<td>Total Fluid Volume</td>
<td>• Current Reservoir Pressure</td>
</tr>
<tr>
<td>Fluid Type</td>
<td>• Current Producing Rate</td>
</tr>
<tr>
<td>Total phi-h</td>
<td></td>
</tr>
<tr>
<td>Permeability Indicator</td>
<td></td>
</tr>
<tr>
<td>Drainage Area</td>
<td></td>
</tr>
</tbody>
</table>
Diagnostic Plot for Selecting Restimulation Candidates, Antrim Shale
Type-Curves For Production Enhancement Assessment

- **Production Data Analysis**
  - Logarithmic Distribution of Fracture Length Results
  - Producing Rate, Mcfd
  - Producing Time, months
  - Xe/Xf = 1 (bottom curve), 1.25, 1.50, 1.75, 2, 3, 5, 7, 10, Infinity (top curve)
  - Match Data:
    - h -- 43.0 feet
    - k -- 0.059 md
    - A -- 108 Acres
    - Xf -- 541 feet
    - EUR -- 2.254 Bcf

- **Arithmetic Average** of Fracture Half-Length Range:
  - Arithmetic Average = 374 feet
  - Median = 352 feet
  - Std Dev = 186 feet

- **Individual Fracture Length Interval Trends**
  - $y = 2229.5x^{0.7218}$
  - $R^2 = 0.6957$
  - $y = 2386.5x^{0.6073}$
  - $R^2 = 0.7259$
  - $y = 3111.1x^{0.5622}$
  - $R^2 = 0.8625$
  - $y = 4040.7x^{0.3384}$
  - $R^2 = 0.2277$

- **NLB 66-04**
  - Actual Rate
  - Simulated Rate
  - Original Forecast

- **Test Well Plots.xls**
Screening Criteria

**Virtual Intelligence**
- Optimized incremental production
  - Stimulation, artificial lift, FWHP

**Type Curves**
- Forecast incremental production
  - Perm, skin, area

**Other**
- No. zones per frac treatment
- Current reservoir pressure
- Current producing rates/ratios
- Historical peak rate, time/prod. since then
- Existence of step-change production drops
Presentation Outline

- Background
- Project Description
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- Future Work
Mocane-Laverne Gas Area, Oklahoma

- Central Anadarko basin
- Beaver/Harper/Ellis Counties
- Council Grove, Tonkawa, Morrow, Chester

- 2nd-largest Midcon gas play (Morrow), after Hugoton Wolfcamp.
- 2nd-largest Morrow field, after Watonga-Chickasha Trend.

- +/-100 well study
- Oneok Resources

Figure reproduced from: Atlas of Major Midcontinent Gas Reservoirs, 1993.
Structure/Stratigraphy*

*Figure reproduced from Atlas of Major Midcontinent Gas Reservoirs, 1993.
### Formation Descriptions

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
<th>Lithology</th>
<th>Gas Atlas Code*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morrow</td>
<td>Lower Pennsylvanian</td>
<td>Sandstone</td>
<td>PN-9A</td>
</tr>
<tr>
<td></td>
<td>Upper Mississippian</td>
<td>Limestone</td>
<td>MS-5</td>
</tr>
</tbody>
</table>

### Reservoir/Fluid Properties*

<table>
<thead>
<tr>
<th>Property</th>
<th>Morrow</th>
<th>Chester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay</td>
<td>20 ft</td>
<td>18 ft</td>
</tr>
<tr>
<td>Porosity</td>
<td>12%</td>
<td>8%</td>
</tr>
<tr>
<td>Water Saturation</td>
<td>38%</td>
<td>30%</td>
</tr>
<tr>
<td>Permeability</td>
<td>25 md</td>
<td>1 md</td>
</tr>
<tr>
<td>Gas Gravity</td>
<td>0.75</td>
<td>0.64</td>
</tr>
</tbody>
</table>

### Well Breakdown

#### Well Omission Summary

<table>
<thead>
<tr>
<th></th>
<th>Zone</th>
<th>Inactive</th>
<th>Completion Date</th>
<th>IHS Data</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>22</td>
</tr>
<tr>
<td>Not Min</td>
<td>14</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>22***</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>43</td>
</tr>
</tbody>
</table>

*Active Wells

**Study well criteria:

- Morrow/Chester completion
- Currently active
- Completion prior to Jan-00
- IHS data available.

***Other Zones included:

- Tonkawa(10)
- Hoover (7)
- Other (5)
## General Well Profiles

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Date</td>
<td>1957-1999</td>
<td>--------</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td>4700-8900</td>
<td>6900</td>
</tr>
<tr>
<td>EUR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Gas (MMcf)</td>
<td>10-8595</td>
<td>2174</td>
</tr>
<tr>
<td>– Oil (Mbbls)</td>
<td>0-47</td>
<td>5</td>
</tr>
<tr>
<td>Current Gas* Rate (Mcfd)</td>
<td>0-263</td>
<td>69</td>
</tr>
</tbody>
</table>

Note: About half of study wells currently produce less than 60 Mcfd.
Completion/Production Practices

Completion
• Morrow typically fractured; many different fluids; older treatments were very small.
• Chester typically acidized; occasionally acid-fractured.

Production
• Some form of artificial lift typically installed at some point to lift liquids.
“Flat File” Design for VI Analysis

**Space & Time**
- X (Long)
- Y (Lat)
- Top Morrow perf.
- Top Chester perf.
- Completion date

**Completion/Stimulation**
- Interval
- Treatment Type
- Fluid Type
- Fluid Volume
- Proppant Volume
- No. Stages

**Reservoir**
- No. perf. intervals
- Net perf. thickness

**Subsequent Events**
- Date
- Interval
- Activity
Test Site Status

• Data Collected
  ➢ IHS Energy
  ➢ In-house production/reserve records
  ➢ Well files

• Challenges being encountered
  ➢ Diversity of producing intervals which change and are reworked over time.
  ➢ Little digital data (except production).
  ➢ Little geologic/reservoir data.

• Status
  ➢ Manually creating “flat-file” for VI analysis.
  ➢ Performing TC analysis.
Next Steps

• Complete VI & TC analyses.
• Develop screening criteria, select candidates.
• Perform remedial work, observe/document results.
Presentation Outline

Background
Project Description
Prior Work
Technology
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Application Guidelines
Future Work
Application Guidelines

**Why**
To boost reserves and economic performance of marginal gas wells.

**Where**
Almost any setting is a valid target (complexity varies however).

**How**
- Build database
- Perform VI & TC analyses
- Select candidates
- Remediate Wells

**When**
Now.

**Who**
Operator.
Observations/Recommendations

- Most costly (analytic) elements are:
  - Data collection/digitization/organization.
  - Reporting (if required)
- Operators should invest in creating a digital database of all available well information (even simple spreadsheets are fine):
  - Any sophisticated analysis will eventually require this.
  - Cost of manually examining well files will eventually exceed investment in database.
- Each field will possess specific nuances:
  - Must capture existing field experience.
  - Design of VI application.
  - Screening algorithm
- Larger-scale programs will provide better overall results due to efficiencies of scale.
Presentation Outline

- Background
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- Current Field Work
- Application Guidelines
- Future Work
Future Work

• Complete analysis of Mocane-Laverne wells, perform/document results of remedial treatments.

• Perform a similar analysis at a second site (sites currently being solicited).

• Technology transfer.
  - Publish results
  - “How To” manual
  - Software

• Completion date:
  - March 31, 2002.
Research Partner Information

**Advantages**
- Assessment of production enhancement for +/- 100 wells.
- Introduction to VI and TC applications.
- Keep tools for future in-house use.

**Requirements**
- Operator of +/- 100 stripper gas wells in a single play.
- Data availability (preferably in electronic format)
- Willingness/ability to perform 1-3 remediation treatments/workovers.
- Agree to release results into public domain.

**Contact**
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