Reservoir Monitoring Consortium (RMC)

Annual Project Review Meeting

An Update on RMC

Fred Aminzadeh,

Los Angeles, CA
October 21, 2014
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>8:00</td>
<td>Registration-Breakfast</td>
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<tr>
<td>8:15</td>
<td>An Update on RMC</td>
<td>Aminzadeh</td>
</tr>
<tr>
<td>8:45</td>
<td>Reservoir Workflow for $\text{CO}_2$-EOR Applications</td>
<td>Karakas</td>
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<tr>
<td>9:15</td>
<td>Hydraulic fracturing in a Kuwait Carbonate field</td>
<td>Najem</td>
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<td>9:45</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Session Title</td>
<td>Speaker(s)</td>
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<td>-------------------------------------------------------------------------------</td>
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<tr>
<td>10:00</td>
<td>Design and Monitoring Fluid Injection to Minimize Induced Seismicity</td>
<td>Eric Matzel, LLNL</td>
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<tr>
<td>10:30</td>
<td>Integrating Micro Seismic and Conventional Seismic Data for Characterizing Fracture Network, A California Case History</td>
<td>Debotyam Maity, Gas Technology Institute</td>
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<tr>
<td>11:00</td>
<td>Gas Reservoir Prediction with Absorption &amp; Anisotropic AVO</td>
<td>Chen</td>
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<tr>
<td>11:30</td>
<td>Microseismic/Electromagnetics for reservoir monitoring</td>
<td>Kurt Strack, KMS Technology</td>
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<tr>
<td>12:00</td>
<td>Lunch</td>
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1:00  Monitoring Risk, A Gulf of Mexico Case History  
      Kelly Rose  
      (NETL)  
      Ghanem  
      (USC)  

1:30  Wellbore Monitoring for Kick Detection  
      Ante  
      URS/USC  
      Rose, Tost,  
      (NETL)  

2:00  New Developments in Reservoir Monitoring  
      Alan Sibbit  
      Schlumberger  

2:30  Towards Optimizing Operational Parameters for  
      K. Nejad  
      Real Time Monitoring of Hydraulic Fracturing  

3:00  Coffee Break
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Presenter</th>
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<tr>
<td>3:00</td>
<td>Reservoir permeability characterization based on microseismic data for a heterogeneous, anisotropic reservoir</td>
<td>Hosseini</td>
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<tr>
<td>3:30</td>
<td>Time lapse Petrophysics for reservoir Monitoring</td>
<td>Donald Hill (HillPetro / USC)</td>
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<tr>
<td>4:00</td>
<td>Experimenting with Microseismic monitoring</td>
<td>Martin Karrenbach.  (SR2020)</td>
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<td>4:30</td>
<td>Advisory Board Meeting- 2014-2015 Priorities</td>
<td>All</td>
</tr>
<tr>
<td>5:00</td>
<td>Concluding Remarks</td>
<td>Fred Aminzadeh</td>
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RMC Objectives

- Identify the current key technology gaps
- Focus on interfaces between different disciplines
- Integrate data, information, expertise and workflows
- Maintain a balance between the short term high impact research and long term needs
- Develop dynamic reservoir monitoring (DRM) workflow
- Focus areas of reservoir types:
  - Shale,
  - Carbonate,
  - Deep water
RMC At a Glance

Sponsors

USC

Strategic & Technical Advisory Board

Problems
- Conventional
- Carbonate
- Shale gas
- HP/HT
- Deep water
- Fractured
- Heavy Oil
- Mature fields

Tools
- Reservoir Engineering
- Signal Processing
- 4D Geophysics
- Nano Technology
- Cloud Comp. HPQ
- Borehole Sensors
- NN/FL/ GI/ PR/AI
- Geomechanics
RMC Hybrid Structure

- **RMC Base Project**
  - Member’s Access to general results of Base RMC
  - Prioritization of Base Project Mix
  - Partial Access to ISP projects (with ISP member concurrence)

- **Individually Sponsored Projects (ISP)**
  - Access to RMC Base Project Results
  - ISP Member focused project
  - Limited distribution of data and results
  - Increased interaction between ISP member and USC
PhD Students

- Magdalene Ante (NETL)
- Ahmed Bubshait (Saudi Aramco)
- Mehran Hosseini
- Nima Jabbari
- Metin Karakas (Chevron Fellowship)
- Debotyam Maity (now with Gas Technology Institute)
- Noha Najem (Kuwait Oil Company)
- Arman Nejad
- Mahshad Samnejad
- Tayeb Tafti (now with Aera Energy)
- Robert Walker (Chevron Fellowship)
USC Reservoir Monitoring Consortium

RMC Base Projects

- Optimize Hydraulic fracturing for shale
- Physical Models to monitor reservoir fluid (with CUP)
- MEQ to Map Reservoir Structure
- Time lapse Petrophysics for RM
- MEQ & Seismic Integration for Shale Reservoirs
- Tomography Based Reservoir Modeling
Optimization of Hydraulic Fracturing stages in Unconventional reservoirs

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<tr>
<th>Parameters</th>
<th>Values</th>
<th>Unit</th>
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<tr>
<td>Model dimensions</td>
<td>3000 x 1510 x 300</td>
<td>ft</td>
</tr>
<tr>
<td>Initial reservoir pressure</td>
<td>2950</td>
<td>psi</td>
</tr>
<tr>
<td>Reservoir temperature</td>
<td>150</td>
<td>°F</td>
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<tr>
<td>Bulk density</td>
<td>161</td>
<td>lbs/ft³</td>
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<tr>
<td>Pressure gradient</td>
<td>0.44</td>
<td>psi/ft</td>
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<td>Bottom hole pressure</td>
<td>500</td>
<td>psi</td>
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<tr>
<td>Horizontal well length</td>
<td>2968</td>
<td>ft</td>
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<td>Production period</td>
<td>20</td>
<td>years</td>
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<tr>
<td>Matrix permeability</td>
<td>(0.00015)*</td>
<td>md</td>
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<td>Matrix porosity</td>
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<tr>
<td>Natural fracture efficient permeability per grid</td>
<td>(0.0001)*</td>
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<tr>
<td>Natural fracture porosity</td>
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<tr>
<td>HF conductivity</td>
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<td>HF spacing</td>
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<td>HF height</td>
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<td>ft</td>
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<td>HF half-length</td>
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<td>ft</td>
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<tr>
<td>Number of HF's</td>
<td>28</td>
<td>stages</td>
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</table>

Rathin Parekh

Shale gas model

The interaction between matrix and fracture subsystem, with a dual permeability model.
Optimization of Hydraulic Fracturing stages in Unconventional reservoirs

Complex Performance index

\[ J = \sum_{k=1}^{K} \left[ \sum_{j=1}^{N_{\text{prod}}} \left( \frac{Q_{g,j}^k \cdot r_g - Q_j}{(1 + b)T^k/365} \right) \right] - \sum_{j=1}^{N_{\text{prod}}} (C_w \cdot j + H_jC_f + H_jC_p). \]

- \( Q_{g,j} \) - average gas production rate of well \( j \) at time step \( k \) [m\(^3\)/day],
- \( r_g \) - gas price [$/m\(^3\)],
- \( Q_{w,j} \) - average water production rate of well \( j \) at time step \( k \) [m\(^3\)/day],
- \( r_w \) is the water disposal cost [$/m\(^3\)],
- \( O_j \) - operating cost of well \( j \) [$/day],
- \( T^k \) - length of the time step \( k \) [days],
- \( b \) - discount rate [%/100/year],
- \( W \) - switch indicating whether a well is drilled or not
- \( C_w \) - base cost for drilling the well to target depth
- \( C_f \) - cost per drilled grid block in target zone
- \( H_j \) - number of hydraulic fracture stages in well
- \( C_f \) - cost per hydraulic fracture stage

Optimization being tried

GA
ANN
Hybrid
1- Complex geological structures
The model has the complex structure: large-scale thrust-structure, the formation of large dip angle, high angle fault, high and steep structure characteristics.

2- Shale Reservoir Model
The model would simulate different fracture networks for different types of shale

Three-dimensional geological structure model

With

Chinese University of Petroleum
Prof Wang, Prof. Yong
Physical Modeling

The profile of 3D model

<table>
<thead>
<tr>
<th>layer</th>
<th>velocity</th>
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<tbody>
<tr>
<td>Surface</td>
<td>2500</td>
</tr>
<tr>
<td>1</td>
<td>3350</td>
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<tr>
<td>2</td>
<td>3700</td>
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<tr>
<td>3</td>
<td>4300</td>
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<td>4</td>
<td>4800</td>
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<td>5</td>
<td>4500</td>
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<tr>
<td>6</td>
<td>4900</td>
</tr>
<tr>
<td>7</td>
<td>5200</td>
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The layer velocity of 3D model

The contour map of a layer
Physical Modeling

The 3D physical model of complex structure (scale is 1: 20000)
RMC Individually Sponsored Projects (ISP)

Next Generation Visualization
In-situ Stresses for hydrofacture
Well log parameters as gas-sand predictors

Real-time Micro-Seismic Monitoring
Monitoring Risk for Oil Spill
MEQ and EM Data for Shale Reservoirs Monitoring,

Monitoring kick and overpressure
HCl with Absorption and Anisotropyic AVO
Advanced Hydraulic Fracturing Test Bed

Saudi Aramco
NETL
KMS

Y
S
X
Z
An integrated approach to enhance efficiency and environmental safety of shale oil and gas production

PI- Fred Aminzadeh
Co-PIs: Mark Zoback
Department of Geophysics, Stanford University
Behnam Jafarpour
Petroleum and Electrical Engineering, USC
Felipe de Barros, Kelly Sanders and Amy Childress
Environmental Engineering Program, USC
Charles Sammis
Earth Sciences, (SCEC)
Martin Karrenbach,
SR2020 Inc.

Industry Sponsor Energy Corporation of America (ECA)
Enhance efficiency and safety of shale production
Enhance efficiency and safety of shale production

- Geomechanical modelling through integrated analysis of minifrac and DFIT tests and geophysical logs supplemented by analysis of microseismic and 3-D seismic data, along with laboratory tests on core samples.
- Discrete fracture network modeling of the stimulated rock volume using data from image logs and microseismicity and estimation of productivity (and productivity over time) of the stimulated reservoir.
- Collection of MEQ data and groundwater samples in different levels and scales and design monitoring wells to analyze the MEQ activity of operation and groundwater quality to prevent any adverse effects during or after hydraulic fracturing.
Enhance efficiency and safety of shale production

Traces of main faults and subsidiary faults in field and in the laboratory. CT-scan slice of the sample's center is shown on the right (Goebel et al. 2013).
• Examine groundwater contamination through surface sampling and numerical modeling of the contamination flow in both surface and subsurface flow and study different scenarios of contamination.

• Characterize injection fluid volume, composition, and injection depth for wells across the US using FracFocus.org and be synthesized into a publicly available database.

• Detail chemical constituents of produced water from a sampling of wells to inform the development of onsite and energy-efficient water recycling operations to help placate concerns regarding seismic events and groundwater contamination arising from poor wastewater management.
Enhance efficiency and safety of shale production

Monitoring survey layout for pre- and post characterization and continuous monitoring

A full scale numerical seismic simulation of a double-couple event in the proposed survey geometry.

Courtesy of SR2020
Conclusions

- Reservoir Monitoring is a truly multi-disciplinary problem
- RMS offers the expertise and know how from different USC entities
- RMC base provides a platform for low cost technology development and application with leveraging opportunities
- RMC ISP offers a focused R&D with the priorities of different companies and other organizations
- Leveraging Opportunities with ISC and other programs