INNOVATIVE APPROACHES FOR COAL BED METHANE WELL AND FIELD HISTORY-MATCHING
Over 35 international clients in 20+ countries

Over 100 projects worldwide since 2008

CBM projects

Regional offices

Representative offices
OBJECTIVES OF THIS TALK

1. Provide practical workflow to conduct production history-matching with coal-bed methane resources
   - Why conventional workflows don’t work
   - Single well history matching as a basis for well and field matching

2. Illustrations of single well history-matching
   - Extent and limitations of the approach
     - Effect of operational perturbations
     - Effect of changing drainage patterns
     - Effect of heterogeneity

3. Applications of the method
   - Improve reservoir characterisation
   - Understand forecasting uncertainty
   - Determine Infill drilling targets
   - Re-invest properties into full field model
CBM at a glance and theoretical profile

Permeability: exclusively from fracture system

‘the ultimate naturally fractured reservoir’

Gas storage: principally adsorbed in matrix
• Released as pressure is dropped
• Capacity at shallow depth much more than conventional storage

Production profile (theoretical):
• Dewatering phase first, then gas production
• Peak occurs (pressure reduction vs. gas desorption)
However… Variability in Well Responses
Producing field in Australia – exhibiting a wide range of type performance
How to conduct production data analysis and history matching?
Problem Statement

Large variability observed between wells at short scales

- Variability of coal properties (isotherm, gas content, etc.)
- Fractured only play – highly variable
- Interplay of physics
  - Desorption vs. ‘Darcy’ flow
  - Matrix shrinkage

Poorly constrained reservoir characteristics at the well

- Seismic not much help
- Log data provides very little information unless advanced and expensive BHI
- Core measurements are limited (coreholes)

Consequently: Traditional 3D modelling workflows are very difficult to implement and less likely to deliver
Classical workflows
Insufficiently constrained static modelling

RESERVOIR CHARACTERIZATION

STATIC MODELLING

INSUFFICIENTLY CONSTRAINED STATIC MODEL!
Assuming that a well can be represented as follows

Average values of:
Gas content, permeability, Ash, relative permeability, skin, isotherm, etc..

Can be simplified to a radial flow problem (2D or 1D)
- Numerical so capture transient

Homogeneous
- Constant properties within drainage area

Can do multi-layer but let’s consider we have a single layer for this example

Main objective is achieving speed
Stochastic History Matching
Process allows for 100’s of matching cases to be generated in minutes

Coupled global optimisation with well forecasting model

Generate multiple matching realisations
Forecast multiple realisations to assess remaining uncertainty
Understand the underlying matching parameter ranges
SPEED IS THE ESSENCE

Single layer, 9 parameters search

~1-2 minutes to find a solution with optimised search and computation algorithm
Technique widely applied for our clients
Australia, India and Indonesia

• Proven capability with short-term pilot production and long-term development production
Applicability and limitation of a single well history-matching technique
Single Well History Matching – image well verification

Infinitely acting field with multiple wells

Bounded field with one centered well

The well ‘cw’ can be perfectly history-matched with a single well whose drainage area is $d^2$

d : distance between 2 consecutive wells

$\text{cw : central well}$

$\text{sw : single well}$

Gas Production Rate [Mscf/day]

Water Production Rate [bbl/day]

Time [days]
**Effect of Dynamic BHP ‘operational perturbations’**

A non-perturbed well is only partially affected by its surrounding wells’ dynamic BHP.

The late life impact is greater as reservoir pressure gradients are evening out.
Effect of Dynamic BHP ‘operational perturbations’

Steady-state: BHP(i) = constant

Transitory: BHP (i) = F(time)

Here we can see the ‘late life impact’ explaining the oscillations in production curves.

T = 3790 days

Field Pressure
Effect of changing Drainage Areas

0 < t < 60 days
Well: shut off
Well: open

0 60 120 180
Time [days]

Surrounding wells' status

0 1

0 < t < 60 days
t > 60 days

‘0’ : well shut off
‘1’ : well open

Drainage area for the central well gets larger, when we shut surrounding wells off at T = 60 days
Effect of changing Drainage Areas

Surrounding wells’ status

Well response migrates from one drainage area solution to another.
Effect of changing Drainage Areas

Steady-state: Drainage Area = constant

Transitory: Dynamic Drainage Area

Steady-state: Drainage Area = constant

Case ‘A’

Case ‘C’

Case ‘B’

T = 1550 days

In order to match as a single well this problem, we need to re-initialise the problem with new boundary conditions.
Heterogeneous Permeability Field

The central well is located in a low permeability zone.

It can be matched with a single well seeing an average property of:
- $K = 15 \text{ mD}$
- Skin = 0.5 (corresponding to a ‘Hawkins’ type skin)
Extension to multiple wells HM

Heterogeneous Permeability Field

This well can be matched with a single well seeing an average property of:

- $K = 42 \text{ mD}$
- Drainage Area = 21 acres

Near well:
- $K$ average = 41 mD
- Area: 14 acres
Applications of SSWHM
Integration into existing workflows

- **STOCHASTIC SINGLE WELL MATCHING**
  - Multiple solutions
  - Understanding uncertainty ranges

- **NETWORK MODEL**
  - Production optimisation and facilities network design
  - Calibration of the well performance and tank models from the DOT.CBM solutions
  - Multiple realisations can be generated and tested

- **PERFORMANCE MAPPING**
  - Evaluation of drainage area for infill drilling assessment – an evolution from classical ‘bubble maps etc’

- **3D MODELS**
  - Static and Dynamic workflow
  - Re-invest matched reservoir properties into the static model
  - Provide calibrated inflow and reservoir dynamics to seed an improved History-Match with 3D model
Example of a full-field match

Multi-layered CBM field, high-quality resource with variable well performance
Deployed the FFHM workflow which resulted in multiple field matches

Diversity of well responses

Structural play partially explaining the production performance differences
Example of a full-field match

Applications of the methodology

Stochastic matching of individual wells

Aggregation into Full Field Matching

Forecasting uncertainty based on individual well FC uncertainty

Data analysis – connected GIIP and reservoir characterisation
Reservoir characterisation

A key value in updating future field development plans and reserves assessment
Validating reserves and forecasting assumptions for other areas, identifying trends

Connected volume to wells

Porosity-permeability

Gas Content, isothermal properties
FROM SINGLE WELL TO FIELD LEVEL MATCHING
Published workflow SPE-167658 (2013)

WELL LEVEL
- Production Data
- Reservoir Characterization
- Single Well History Matches

FIELD LEVEL
- Geo-statistical Constraints
- Matched Drainage Areas Maps
- Field Matches Filtering

SPE-167658-MS• Multi-Realisation Full-Field History-Matching For CBM Resources a New Approach with Global Optimisation Coupled with Geo-Statistical Filtering • Laurent Alessio
Incorporating fracture network interpretation
Comparison between isotropic and anisotropic generation

Borehole image interpreted density for each fracture set (azimuth/direction) from ‘Rose diagrams’

For each natural fracture set, we assume that the measured fracture density can be converted to a permeability modulus along its direction

Fracture Modelling

Isotropic Drainage Areas

Anisotropic Drainage Areas
### Average Properties Maps

#### Field Match 1

<table>
<thead>
<tr>
<th>Area</th>
<th>Well1</th>
<th>Well2</th>
<th>Well3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area1</td>
<td>100</td>
<td>120</td>
<td>300</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.0008</td>
<td>0.0014</td>
<td>0.002</td>
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<tr>
<td>Perm</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

#### Field Match 2

<table>
<thead>
<tr>
<th>Area</th>
<th>Well1</th>
<th>Well2</th>
<th>Well3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area1</td>
<td>150</td>
<td>120</td>
<td>280</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.0007</td>
<td>0.0004</td>
<td>0.0018</td>
</tr>
<tr>
<td>Perm</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>
3D Static Modeling

Individual property maps from each field match

Import into 3D static model as trend maps

Reservoir characterization

History Matched 3D Model

Production Data

Static Modelling
Infill Drilling Location
The Workflow

**One scenario**
Drainage Scenario

**Multiple Scenario**
Pressure Likelihood Map

One scenario + Multiple Scenario

Treatment

Infill Drilling Location

\[ P = P_e + C \ln \left( \frac{r}{r_e} \right) \]
Infill Drilling Location
Infill Drilling Filter

We set a pressure threshold, and the map displays only the location with an estimated pressure above threshold.

These are the areas with the highest pressure profile => The most interesting areas to explore.

These are the best locations for future infill drilling wells.
WE ENJOY SOLVING YOUR PROBLEMS

Thank you for your attention

More information and technical papers on
www.leap-energy
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