Analyzing Enhanced Oil Recovery using SAS

Multi-Dimensional Analytics and Visualization of Fluid Communication

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GOAL

Develop an analytical tool for waterflooded fields which will assist in:

- monitoring,
- analyzing,
- understanding, and
- predicting
  - fluid communication (RESPONSES)
  - fluid production.

- Optimizing water usage and oil production
- Plan new waterflood activity
- Discover unknown communication between different pools

New applications (environmental)
New Tool

Characteristics
- Simple
- Uses only public domain data (Injection/Production)
- No assumptions
- No streamlines, no tubes, no grid blocks, etc.
- Captures ‘actual’ different fluid responses in specific time window
- Estimates come with ‘significance level’
- Shows no communication or detrimental responses
- Can detect communication between different pools/fields
- Detects communication prior to waterfloods
- FAST
- Good for new players without experience
- Good for studies before acquisitions
- Brings unbiased view and differences between what is good, bad, and maybe
- Enables VISUAL EXPLORATION of many dimensions
STEPS in Studies

- Detect and measure waterflood responses
- Visualize them in time
- Integrate responses with geological, completion, treatment, ..., data sets
- Predict future responses and production
- Optimize resources (Minimize water, solvents, etc.) and Maximize oil production
Published

Journal of Canadian Petroleum Technology, vol. 40, No. 6
Journal of Canadian Petroleum Technology, No. 5, Vol. 46
SPE 50430
and more

SYLVAN LAKE
PEKISKO B POOL SCHEMATIC CROSS-SECTION

other fields:
  Valhalla, Mirage,
Golden Lake, Goose River,
Swan Hills, Midale
Oil Response - Definition
Visualization - Star Diagram

Response = Correlation between series
Waterflood Response Parameters

- Oil/gas/water/total fluid responses at lag=0
- Oil/gas/water/total fluid lagged responses
- Time lags corresponding to the lagged responses
- Combination of two responses defined as: Response Type
  - oil-water
  - oil-gas
  - oil-total fluid

Can be associated with flow units and geological units

Estimates come with confidence level
Multi-dimension Visualization
Spine Diagram

Injector
Producer
Missing Data
Positive Response
Negative Response

Scale=0-1
(center-out circle)
Response Time Lag < 6 months
otherwise

Radius=function of
(Well's injection/Field's Injection
or
Well's Production/Field's Production)
Composite Spine Diagram
Large Scale - Oil Responses
Composite Spider Diagram

*Example: Oil Responses $\geq 0.5$ or/and Distance $< 2500\text{m}$

Radius = $f($normalized injection or production$)$
Composite Spider Diagram
with horizontal wells
Oil Responses >=0.5
MIDALE example; paper No. SPE 50430
Combination of Responses
Response Type (oil & fluid) => Flow Units

Response type = f (oil response and fluid/water/gas response)
Application of Responses

- Finding communication paths and boundaries
- Mapping flow units
- Identifying ineffective injectors
- Identifying producers without support
- Improving production allocation estimates
- Identifying areas with fluid loses
- Predicting future responses
- Developing infill programs
- Generating correction maps for reservoir simulation.
Data Sets:
- Geological (all possible)
- Completion
- Treatment
- Waterflood Responses

Predictive modeling

Target (Predicted variable):
- PRODUCTION Rate
- High Rate PRODUCTION PROBABILITY (top 25 percentile)
  \[===>\] Rank = Good or Poor.

Advanced Visualization
Modeling Example

Data:

- Lagged and non-lagged responses, time lags, and response types
- Pekisko B top subsea
- Pekisko B subsea of oil-water contact
- Pekisko B netpay

Target: Probability of oil production in the highest 25 percentile

Three model types:

- Logistic regression
- Decision tree
- Neural network

Decision tree can be the best performer
Decision Tree = Set of English Rules

IF $16.0 \leq P_{\text{NET\_OIL}}$ and $C_{\text{OIL\_0}} < -0.045$ THEN

N : 25
0 : 20.0%
1 : 80.0%

IF $16.0 \leq P_{\text{NET\_OIL}}$ and $-0.045 \leq C_{\text{OIL\_0}} < 0.26$ and $P_{\text{SUB\_TOP}} < -1252.21$ THEN

N : 23
1 : 65.2%
0 : 34.8%
Modeling Outcome

- Integrated geological and waterflood response parameters.
- Developed predictive models for the oil production rates during waterflood.
- Models predicted the probability of a GOOD well.
- Developed and tested Regression, NN, and Decision Tree models.
- Decision trees provided the best predictive models.
- Model based on decision tree had two to four times better success rate than the observed rate.
- Profit and fixed cost matrices helped in predicting: \( \text{Return} = \frac{\text{costs}}{\text{return(fixed, true positive, false positive, true negative, and false negative predictions)}} \).
ADVANTAGES

- Scientific
- Consistent (no bias)
- Fast
- Based on public data
- Low cost
- 200 patterns and 500+ wells NO PROBLEM
- Links responses to other data sets
- Leads to better understanding
- Helps to:
  - monitor performance
  - make production decisions
  - predict/optimize return.
SAS as Development and Implementation Tools

**DEVELOPMENT**
- Data Integration
- Data Cleansing
- Data Transformation
- Normalization
- Log Transformation
- Simple Stats
- Time Series Correlation
- Custom Ranking
- Graphics/Visualization
- Regression, Neural Net, and Decision Tree Models

**IMPLEMENTATION**
- SAS Programs Data Steps
- SAS Programs Macros
- SAS Procedures
- SAS/EM Exported Model Code
- SAS Visual Explorer

**Comment:** Development Prototype becomes Implementation Code Version 1