EVOLUTION OF
RESERVOIR MANAGEMENT TECHNIQUES

From Independent Methods
to an Integrated Methodology

Impact on Petroleum Engineering Curriculum, Graduate
Teaching and Competitive Advantage of Oil Companies


Alain C. Gringarten
Imperial College, London
CONTENT

■ RESERVOIR MANAGEMENT PROCESS
  • DEFINITION
  • OBJECTIVES
  • METHODOLOGY
  • IMPLEMENTATION

■ IMPACT ON COMPETITIVE ADVANTAGE

■ PETROLEUM ENGINEERING CURRICULUM
RESERVOIR MANAGEMENT

- APPLICATION OF AVAILABLE TECHNOLOGY AND KNOWLEDGE

- TO A RESERVOIR SYSTEM

- WITHIN A GIVEN MANAGEMENT ENVIRONMENT

- IN ORDER TO CONTROL OPERATIONS AND MAXIMISE ECONOMIC RECOVERY
OBJECTIVES
OF RESERVOIR MANAGEMENT

- DECREASE RISK
- INCREASE OIL AND GAS PRODUCTION
- INCREASE OIL AND GAS RESERVES
- MINIMISE CAPITAL EXPENDITURES
- MINIMISE OPERATING COSTS
- MAXIMISE RECOVERY
RESERVOIR MANAGEMENT TOOL:

MODELLING THE RESERVOIR BEHAVIOUR TO MAKE DECISIONS

ACQUIRE DATA → MODEL RESERVOIR BEHAVIOUR → PREDICT PRODUCTION & CALCULATE RESERVES
THE MODELLING PROCESS

1. IDENTIFICATION OF A RESERVOIR MODEL
   RESERVOIR CHARACTERISATION (INVERSE PROBLEM)

2. CALCULATION OF THE RESERVOIR MODEL
   BEHAVIOUR  UPSCALING AND SIMULATION

3. MATCHING OF RESERVOIR SYSTEM PAST
   PERFORMANCE  HISTORY MATCHING (DIRECT PROBLEM)

4. PREDICTION OF RESERVOIR SYSTEM FUTURE
   PERFORMANCE (DIRECT PROBLEM)
RESERVOIR MANAGEMENT PROCESS

Static Information

Geology
Geophysical
Geochemistry
Petrophysics
Geomechanics
Fluids
Flowmetry
Well testing
Production
Tracers

Dynamic Information

Reservoir Model
Simulation Model
Calibrated Simulation Model

Development Scenario
Pipeline & Facilities Model
Economic Model

RESERVOIR MANAGEMENT DECISIONS

©1997 by Alain C. Gringarten
THE RESERVOIR MANAGEMENT PROCESS

DATA

RESERVOIR CHARACTERISATION

PREDICTION OF RESERVOIR PERFORMANCE

FIELD DEVELOPMENT PLAN

PREDICTION OF WELL PERFORMANCE

RESERVOIR MANAGEMENT DECISIONS

IMPLEMENTATION

INFORMATION

KNOWLEDGE

WISDOM

© 1997 by Alain C. Gringarten
RESERVOIR CHARACTERISATION

DATA

INTERPRETATION MODELS

RESERVOIR MODEL

SIMULATION OF RESERVOIR MODEL BEHAVIOUR

© 1997 by Alain C. Gringarten

Production data

Well Flow Model

Prediction of Well Performance

Completion design
Stimulation
Artificial lift
Improvement of Well Performance

Calibrated Simulation Model

Simulation Model
Black Oil/Compositional/Thermal

Upscaling

(Up-scaling)

History Matching

Reservoir Model

Reservoir Model

Development Scenario

Prediction of Reservoir Performance

Prediction of Field Performance

Decline Curve Analysis

Production Infrastructure
Health, Safety and Environment

Pipeline & Facilities Model

Economic Model

RESERVOIR MANAGEMENT DECISIONS
RESERVOIR CHARACTERISATION

- INTERPRETATION OF DATA

  >> STATIC INTERPRETATION MODELS (DESCRIPTION)
  
  GEOPHYSICS, GEOLOGY
  GEOCHEMISTRY
  PETROPHYSICS

  >> DYNAMIC INTERPRETATION MODELS (BEHAVIOUR)
  
  GEOMECHANICS
  WELL TESTS, TRACERS
  FLOWMETRE SURVEYS
INTERPRETATION MODELS

10 layers

Petrophysical Data

Well test Data

2 media

≤10 permeabilities

Tracer Data

Production Logging Data

Identification of producing layers

Flow rate

Depth

Petrophysical Model

Well test Model

Production Logging Model

Concentration vs Time

Flow rate vs Depth
INTEGRATION OF INTERPRETATION MODELS

Geological Model
Geophysical Model
Geochemical Model
Petrophysical Model
Geomechanical Model
Fluid Model
Well test Model
Tracer Model
Production Logging Model
Production Data
Fluid Data
Well test Data
Tracer Data
Production Logging Data
Geophysical Data
Petrophysical Data
Geochemical Data
Geomechanical Data
Geochemical Data
Geophysical Data
Petrophysical Data
INTEGRATION OF INTERPRETATION MODELS

- DETERMINISTIC TECHNIQUES

- STOCHASTIC TECHNIQUES
  - >> INTERPOLATION BETWEEN SPARSE DATA (WELLS) AND EXTRAPOLATION
  - >> CORRELATION AND ORDERING OF INFORMATION
  - >> INTEGRATION OF INFORMATION (CONDITIONING) FROM DIFFERENT DATA SOURCES WITH DIFFERENT LEVELS OF RELIABILITY
  - >> GENERATION OF MULTIPLE, EQUIPROBABLE REALISATIONS OF THE RESERVOIR (PARAMETER DISTRIBUTIONS)
  - >> QUANTIFICATION OF UNCERTAINTIES
Once the reservoir model is constructed, one must verify that this reservoir model is consistent with all available information and interpretation models.

This means that the reservoir model must reproduce all data acquired:

- the seismic,
- logs, etc...,
- well tests.
**Data type 1**
- Identification
- Consistency Verification
- Interpretation Model for Data Type 1

**Data type 3**
- Identification
- Consistency Verification
- Interpretation Model for Data Type 2

**Data type 3**
- Identification
- Consistency Verification
- Interpretation Model for Data Type 3

**Integration into Reservoir Model**
- Simulate Data Type 1
  - Match Data Type 1
  - RESERVOIR MODEL

- Simulate Data Type 2
  - Match Data Type 2
  - RESERVOIR MODEL

- Simulate Data Type 3
  - Match Data Type 3
  - RESERVOIR MODEL

| Identification | Consistency Verification | Interpretation Model for Data Type 1 | | Interpretation Model for Data Type 2 | | Interpretation Model for Data Type 3 |
|---------------|--------------------------|--------------------------------------|---------------------------------|--------------------------------------|---------------------------------|
| YES           | YES                      | YES                                  | YES                             | YES                                  | YES                             |
| NO            |                          | NO                                   |                                 | NO                                   |                                 |
| YES           |                          | NO                                   |                                 | YES                                  |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
| YES           |                          | NO                                   |                                 |                                       |                                 |
| NO            |                          |                                       |                                 |                                       |                                 |
VERIFICATION OF RESERVOIR MODEL FLOW BEHAVIOUR

Static Information

Dynamic Information

Reservoir Model

Simulation Model
Black Oil/Compositional/Thermal

Calibrated Simulation Model

(Up-scaling)

(History Matching)

Reservoir Management Decisions

Development Scenario

Pipeline & Facilities Model

Economic Model

© 1997 by Alain C. Gringarten

DATA

INTERPRETATION MODELS

RESERVOIR MODEL

SIMULATION OF RESERVOIR MODEL BEHAVIOUR

Production data
RESERVOIR MODEL FLOW BEHAVIOUR

- Usually approximated with numerical simulator

- Different flow simulators may be required for different flow data
  - Complexity of simulator function of performance to be simulated (Black Oil, Compositional, Thermal, Chemical)
  - Well test data require high resolution near wells
  - Gridding for existing numerical simulators coarser than for reservoir model (upscaling required)

- Simulation of very large reservoirs or of local heterogeneities requires:
  - Several hundred thousand cells, or
  - New mathematical formulations (Adaptive gridding, Streamline simulators,....)
RESERVOIR MODEL FLOW BEHAVIOUR VERIFICATION

- RESERVOIR MODEL FLOW BEHAVIOUR CONSISTENCY IS VERIFIED BY COMPARING:
  - OBSERVED DATA FROM WELLS (GOR, WOR, ...), and
  - CORRESPONDING RESPONSES FROM NUMERICAL SIMULATOR (HISTORY MATCHING)

- POSSIBILITY TO MATCH SATURATION FRONT LOCATIONS BETWEEN WELLS OBTAINED FROM REPEATED 3-D SEISMIC SURVEYS (RESERVOIR MONITORING)
HISTORY MATCHING

- MATCH BETWEEN DATA AND MODEL CALCULATED BEHAVIOR CAN BE Refined BY ADJUSTING RESERVOIR MODEL PARAMETERS WITHIN LIMITS CONTROLLED BY CONDITIONING

- ADJUSTMENT CAN BE MADE EASIER AND FASTER WITH STATISTICAL OPTIMISATION METHODS (ADAPTIVE HISTORY MATCHING) AND EXPERT SYSTEMS

- LACK OF SATISFACTORY MATCH WITHIN LIMITS CONTROLLED BY CONDITIONING REQUIRES MODIFYING THE RESERVOIR MODEL (RESERVOIR CHARACTERISATION)
Interpretation Models

Integration into Reservoir Model

Verify Reservoir Model (Synthetic seismograms, logs, well tests, production...)

RESERVOIR MODEL

Another Model?

END
PRODUCTION PREDICTION

FOR PREDICTING PRODUCTION, THE RESERVOIR SIMULATOR MUST BE COUPLED WITH:

- WELL MODELS AND
- A SURFACE FACILITIES SIMULATOR
PRODUCTION PREDICTION

Static Information

Dynamic Information

DATA

INTERPRETATION MODELS

RESERVOIR MODEL

SIMULATION OF RESERVOIR MODEL BEHAVIOUR

Integration

Reservoir Model

(Upscaling)

Simulation Model

Black Oil/Compositional/Thermal

(History Matching)

Calibrated Simulation Model

Prediction of Reservoir Performance

Prediction of Field Performance

Production Infrastructure

Health, Safety and Environment

Production data

Well Flow Model

Prediction of Well Performance

Completion design

Stimulation

Artificial lift

Improvement of Well Performance

© 1997 by Alain C. Gringarten

Development Scenario

Pipeline & Facilities Model

Economic Model

RESERVOIR MANAGEMENT DECISIONS
DECLINE CURVE ANALYSIS

Static Information

- Geology
- Geophysics
- Geochemistry
- Petrophysics
- Geomechanics
- Fluids
- Flowmetry Survey
- Well testing
- Production Logging Model

Dynamic Information

- Calibrated Simulation Model
- Prediction of Reservoir Performance
- Prediction of Field Performance
- Well Flow Model
- Prediction of Well Performance
- Completion design
- Stimulation
- Artificial lift
- Improvement of Well Performance
- Production Infrastructure
- Health, Safety and Environment

DATA

- Interpretation Models
  - Geological Model
  - Geophysical Model
  - Geochemical Model
  - Petrophysical Model
  - Geomechanical Model
  - Fluid Model

RESERVOIR MODEL

- Simulation of Reservoir Model Behaviour
  - Integration
  - Reservoir Model
    - Simulation Model
      - Black Oil/Compositional/Thermal
      - (History Matching)
  - Calibrated Simulation Model
    - (Upscaling)
    - Prediction of Reservoir Performance
    - Prediction of Field Performance

Development Scenario

- Economic Model
- Pipeline & Facilities Model

© 1997 by Alain C. Gringarten
RESERVOIR SIMULATION (1960's to 1970's)

Data Interpretation Models

Geology
Geophysics
Geochemistry
Drilling
Petrophysics
Geomechanics
Fluids
Flowmetre Survey
Well testing
Tracers

Reservoir Model

Integration

Simulation Model
Black Oil/Compositional/Thermal

(Upscaling)

Calibrated Simulation Model

Prediction of Reservoir Performance

Prediction of Field Performance

Development Scenario

Pipeline & Facilities Model

Economic Model

Reservoir Management Decisions

Production Infrastructure
Health, Safety and Environment

Production data

Prediction of Well Performance

Completion design
Stimulation
Artificial lift
Improvement of Well Performance

© 1997 by Alain C. Gringarten
RESERVOIR SIMULATION (1980’s)

Static Information → Dynamic Information

Simulation Model
Black Oil/Compositional/Thermal

Calibrated Simulation Model

Prediction of Reservoir Performance

Prediction of Field Performance

Development Scenario
Pipeline & Facilities Model
Economic Model

Production Infrastructure
Health, Safety and Environment

©1997 by Alain C. Gringarten
FREQUENTLY ASKED QUESTION

HOW MUCH OF THIS PROCESS DO WE NEED TO GO THROUGH?

NEED TO QUANTIFY THE RISK
IMPLEMENTATION
THROUGH NEW TECHNOLOGY

- STOCHASTIC MODELLING
- ADAPTIVE HISTORY MATCHING
- RESERVOIR MONITORING
- NEW MATHEMATICAL FORMULATIONS FOR SIMULATORS
- MULTIPHASE PIPELINE SIMULATORS
- MASSIVE PARALLEL PROCESSING
- KNOWLEDGE BASE SYSTEMS
- COMPUTER AIDED PRODUCTION (CAP) TOOLS
COMPUTER AIDED PRODUCTION (CAP) TOOLS

- THE POWERFUL AND PROVEN COMPUTER TECHNOLOGIES

- THAT HAVE BEEN USED BY SPECIALISTS

- BEING MADE AVAILABLE TO AND USABLE BY THE PRACTISING PROFESSIONAL
NEEDS OF THE PRACTISING PROFESSIONAL

- EASE-OF-USE
- PRODUCTIVITY

- TRANSPARENT TECHNOLOGY
- TASK ORIENTED APPROACH
- KNOWLEDGE BASED SYSTEMS

- METHODOLOGY (HENCE REPEATABILITY)
CONTENT

- RESERVOIR MANAGEMENT PROCESS
  - DEFINITION
  - OBJECTIVES
  - METHODOLOGY
  - IMPLEMENTATION

- IMPACT ON COMPETITIVE ADVANTAGE

- PETROLEUM ENGINEERING CURRICULUM
COMPETITIVE ADVANTAGE

IF TOOLS BECOME STANDARD

- METHODOLOGY
- SOFTWARE

COMPETITIVE ADVANTAGE MUST BE

- THE UNDERSTANDING OF FUNDAMENTALS
- KNOW-HOW

Example: Well Test Analysis
WELL TEST ANALYSIS

BREAKTHROUGH IN THE 1980’S

- FROM INDIVIDUAL METHODS GIVING DIFFERENT ANSWERS TO AN INTEGRATED METHODOLOGY BASED ON SIGNAL THEORY
- WELL TEST ANALYSIS SOFTWARE
- PERSONAL COMPUTERS
- DIFFERENT INTERPRETERS USING THE SAME METHODOLOGY GET THE SAME ANSWERS

SIDE EFFECTS

⇒ ERRONEOUS ANALYSES, FASTER

SOLUTION

⇒ EDUCATION / TRAINING
CONTENT

- RESERVOIR MANAGEMENT PROCESS
  - DEFINITION
  - OBJECTIVES
  - METHODOLOGY
  - IMPLEMENTATION

- IMPACT ON COMPETITIVE ADVANTAGE

- PETROLEUM ENGINEERING CURRICULUM
NEW CURRICULUM
SPECIALISTS THAT KNOW HOW TO WORK EFFECTIVELY IN MULTI-DISCIPLINARY TEAMS

Fundamental Understanding of:

Reservoir Characterisation, Reservoir Modelling, Reservoir Simulation, and Field Management

The Processes for Integrating and Processing All Available Information in Order to Make Reservoir Management Decisions

- Work Flow Concepts
- Links Between the Various Types of Data
Follow the reservoir management process
EXAMPLE:
THE MSc IN PETROLEUM ENGINEERING AT IMPERIAL COLLEGE

THE RESERVOIR MANAGEMENT PROCESS

MODULE 1: FUNDAMENTALS
MODULE 2: RESERVOIR CHARACTERISATION
MODULE 3: WELL PERFORMANCE
MODULE 4: RESERVOIR PERFORMANCE
MODULE 5: FIELD DEVELOPMENT

DATA

PREDICTION OF RESERVOIR PERFORMANCE
PREDICTION OF WELL PERFORMANCE
FIELD DEVELOPMENT PLAN
RESERVOIR MANAGEMENT DECISIONS

GROUP FIELD PROJECT

INDUSTRY PRESENTATIONS

KNOWLEDGE WISDOM INFORMATION DATA

IMPLEMENTATION

CENTRE FOR PETROLEUM STUDIES

Imperial College, London
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- **Fundamental / Application / Support courses**
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience
MSc in PETROLEUM ENGINEERING

RESERVOIR CHARACTERISATION FUNDAMENTALS

- Petroleum Geology, Petroleum Geophysics, Rock Properties
- Geological Field trip
- Reservoir Geology, Geophysics and Geochemistry
- Petrophysics & Formation Evaluation
- Fluid Sampling & Analysis
- Production Logging
- Well Test Analysis
- Maureen Group Project (Reservoir Characterisation)
- Geomechanics
- Well Performance
- Reservoir Performance
- Field Development
- Maureen Group Project (Colin Wall Award)
- Individual Research Project

MSc in PETROLEUM GEOSCIENCE

- Development Geology and Reservoir Modelling
- Geophysics
- Structural & Stratigraphic Analysis of Sedimentary Basins
- Integration into Reservoir Model
- Petrophysics & Formation Evaluation
- Basin Modelling
- Structures, Fluids & Pressures
- Petroleum Economics
- Geostatistics
- Sequence stratigraphy
- Group project (Barrel Award)
- Individual Research Project
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience
- Teach prevailing commercial software
MSc Specifications

- Follow the reservoir management process
- Lectures only by experts in their fields
- Students with fundamental background
- Fundamental / Application / Support courses
- Block teaching
- Lectures/notes coordinated and integrated
- Integration with Petroleum Geoscience
- Teach prevailing commercial software
- Use actual field data
Use of field data

- Tutorials for taught courses
- Group field project
  - Phase 1: Reservoir characterisation
    16 teams (Petroleum Engineering + Geoscience)
  - Phases 2: Production planning
    8 teams (Petroleum Engineering)
  - Phase 3: Field development
    8 teams (Petroleum Engineering)
- Individual research projects
Field data: Maureen Field

- Block 16/29a (UK sector of the North Sea)
- Phillips UK operator
- 1983-1999
- 4 appraisal, 12 production and 7 water injection wells

seismic traces and interpreted maps; geological maps; core photographs; routine and special core analysis reports; PVT analysis reports; RFT data; DST and production test data; monthly production data
Field data: Maureen Field
Maureen Group Field Project

Phase 1: Reservoir characterisation
10 days, December

- 5-6 wells
- STOIIP
- Reserve estimates
- Preliminary 3D model

![Graphs and charts showing reservoir characteristics and data]

Fractional Porosity vs Permeability, mD

Depth, ft vs RCAL Porosity

Oil, MMbbl vs STOIIP

Probability: P10, P50, P90, Maximum, Most Likely, Minimum

Elapsed time, ∆t (hours) vs Pressure Change, ∆p, and Derivative (psi)

[Graph legends and data points]

Centre for Petroleum Studies
Imperial College, London
Maureen Group Field Project

Phase 2: Well placement & Production Optimization
6 days, February

- simulation model
- optimized well placement plan
- oil recovery
- cumulative oil production
- optimized well design
- artificial lift options
- a drilling plan
- casing design

[Graphs and diagrams related to well placement, oil recovery, and well design are shown.]
Maureen GroupField Project

Phase 3: Development plan
10 days, March

- improved recovery plan
- surface production facilities
- HSE plan
- economic viability
- abandonment plan
- assessment of risks
- Colin Wall prize

Diagram:
- Process flow diagram showing various components such as separators, dehydrators, and compressors.
- Graph showing NPV over time.
- Graph showing % change from base case value.
THE ULTIMATE RESERVOIR MANAGEMENT GOAL

■ TO MODEL A PETROLEUM RESERVOIR AND ASSOCIATED WELL AND SURFACE FACILITIES WITH SUCH AN ACCURACY

■ THAT ON-GOING PREDICTIONS CAN BE USED WITH CONFIDENCE TO OPTIMISE PRODUCTION OPERATIONS, INCREASE RECOVERY AND REDUCE OPERATING COSTS

■ THEREBY SUBSTANTIALLY INCREASING ECONOMIC RETURN WITHIN MANAGEMENT GUIDELINES