Reservoir Simulation

Instructors: Dr. Turgay Ertekin and Dr. Maghsood Abbaszadeh
Duration: 5 days
Level: Basic - Intermediate

Course Objectives and Description
This five-day course is designed for participants who do not have extensive prior knowledge of reservoir simulation technology. During the first two days of the course, reservoir simulation equations using continuum principle will be discussed for multiphase (three-phase) flow conditions. Then, these equations will be collapsed to single-phase and two-phase flow problems to familiarize the participants with the different stages of reservoir simulation technology. Different gridding techniques and implementation of different boundary conditions at the external and internal boundaries will be discussed together with wellbore coupling. After reviewing the fundamentals of reservoir simulation, the third day of the course will consist of an overview of specialized reservoir simulators with emphasis on their respective critical components. In this day examples of field applications of reservoir simulations to several case histories covering natural depletion, waterflood, CO2 and gas injection, fractured reservoirs, and unconventional shale gas systems will be illustrated.

During the last two days of the course nine different hands-on tutorial exercises using CMG commercial simulators will be presented. During these tutorials, participants will have an opportunity to work on example problems involving conventional and unconventional reservoir simulation problems, simulation of thermal and non-thermal enhanced oil recovery techniques of steam and CO2 injections, gas condensate reservoir and waterflooding. At the completion of the course participants will acquire a good understanding of different types of reservoir fluid flow equations and their respective numerical solutions, and will have an opportunity for a number of hands on exercises on different systems.

Dr. Turgay Ertekin, has been in the forefront of reservoir simulation technologies for the last three decades and is the principal author of the SPE textbook entitled Basic Applied Reservoir Simulation. Dr. Abbaszadeh has extensive reservoir simulation expertise of various field applications of simulation technologies that will enable a rich hand-on knowledge transfer to participants in the course.

Who Should Attend
Reservoir engineers, geologists, geophysicists and petrophysicists

Course Content

Day 1

1. INTRODUCTION
   - Introduction to the Course
   - Course description
   - Course learning objectives
   - Competencies
   - Course components
• Introduction to Reservoir Simulation
  - What is reservoir modeling?
  - Basic components of simulation
  - Basic steps of a simulation study
  - Why model the reservoir?
  - What questions can a reservoir model answer?

• Review of Building Blocks of Reservoir Modeling
  - Review of reservoir rock and fluid properties
  - Reservoir characterization
  - Steady-state and unsteady-state flow concepts
  - reservoir rock and fluid interactions

• Finite-Difference Operations
  - Finite-difference model
  - finite-difference operators
  - Taylor series expansion

2. GOVERNING FLOW EQUATIONS AND BOUNDARY CONDITIONS
• Review of Governing Flow Equations
  - Review of flow equations
  - Multi-phase flow equation
  - Single-phase incompressible flow equation
  - Single-phase slightly compressible flow equation
  - Single-phase compressible flow equation

• Grid types, Boundary Types, Boundary And initial Conditions
  - Major grid types
  - Body-centered grids
  - Mesh centered grids
  - Grid types and boundary conditions
  - Dirichlet type boundary condition
  - Neumann type boundary condition
  - Internal and external boundaries
  - Wellbore model and its coupling

3. SOLUTION METHODS FOR SYSTEMS OF LINEAR ALGEBRAIC EQUATIONS
• Matrix Equation and Direct and Iterative Methods.
  - Coefficient matrices for 1D, 2D and 3D problems
  - Direct solution methods
  - Grid-ordering methodologies
  - Gaussian elimination
  - Thomas’ algorithm
  - Jacoby’s method
  - Gauss-Seidel method
  - Successive over-relaxation techniques
  - Conjugate gradient method
Examples with Iterative Solvers
- Example with Gauss-Seidel algorithm
- Example with point-wise successive over-relaxation algorithm.

4. SOLUTION OF SINGLE PHASE FLOW EQUATIONS
- Single-phase Incompressible, Slightly Compressible and Compressible Flow Problems
  - Coefficient matrices for 1D, 2D and 3D problems
  - Transmissibility coefficient
  - Harmonic averaging
  - Handling of weak and strong nonlinearities in transmissibility terms
  - Representation of the problem using strongly implicit procedure notation (SIP)
  - Generalized Newton-Raphson protocol
  - Incremental and cumulative material balance checks

Day 2

5. MULTI-COMPONENT, MULTI-PHASE FLOW AND BLACK OIL AND COMPOSITIONAL SIMULATION
- Compositional Formulation
  - Compositional simulation equation development
  - Inventory of equations and unknowns in compositional formulation
  - How to collapse the compositional formulation to multi-phase formulations
  - Black-oil formulation

- Review of Rock and Fluid Properties for Black-oil Simulation
  - Porosity and permeability
  - Viscosity
  - Density
  - Formation volume factor
  - Solution gas oil ratio
  - Relative permeability concept
  - Relative permeability models
  - Capillary pressure phenomena
  - Leverette J-Function

- Well Representation and Coupling to Multiphase Flow in Porous Media and Vertical Multi-layer Well Models
  - Coupling of wellbore model to reservoir flow equations
  - Boundary condition specifications at the wellbore
  - Challenges in wellbore specifications
  - Inflow performance relationships
  - Peaceman’s wellbore mode
  - Equivalent wellblock radius
  - Numerical representation of horizontal wells
  - Wells penetrating multilayer wells
  - Pressure and rate specified wells
Solution Methods for Multi-phase Flow Equations
- Implicit pressure explicit saturation method
- Simultaneous solution method
- Fully implicit method
- Newton-Raphson protocol as implemented to multiphase flow problems

6. SPECIAL TOPICS IN RESERVOIR SIMULATION
- Variable Bubble Point Formulation
  - Description of variable bubble point problem
  - Switching of unknowns
- Advanced Solution Methods, Criteria for Selecting Grid Size and Time Step Size
  - Conjugate gradient and bi-conjugate gradient methods
  - Pre-conditioned conjugate gradient and pre-conditioned bi-conjugate gradient methods
  - Stabilized conjugate gradient method
- Conducting a Field Study
  - Preliminary phases of a simulation study
  - Use of pseudo functions
  - Designing the simulation runs
  - Post-simulation studies
  - Report preparation
  - Steps of a simulation study
  - Reservoir characterization and simulation
  - Well management
- Examples of Challenging Reservoir Simulation Problems
  - Representation of complex well structures
  - Local grid refinement techniques
  - Thermal recovery simulation studies
  - Integrated reservoir models
  - Parallel simulation

Day 3

7. SPECIALIZED RESERVOIR SIMULATORS
- Special Purpose Reservoir Simulators
  - Compositional model
  - Gas reservoir simulators
  - Dual porosity reservoir simulators
  - Unconventional gas reservoir simulators
    - Coalbed methane
    - Shale gas reservoirs

8. RELATIONSHIPS BETWEEN RESERVOIR SIMULATION EQUATIONS AND CLASSICAL RESERVOIR AND PRODUCTION ENGINEERING APPROACHES
- Putting It in Perspective
  - Sequential process of a simulation study
- Material Balance Equation and Reservoir Simulation Equations
  - Simulation equations and classical material balance formulation

- Well Test Analysis Model
  - Classical well test analysis model and reservoir simulation equations of a simulation study

9. REVIEW OF RESERVOIR SIMULATION APPLICATIONS

- Field Application Considerations
  - History matching
  - How to set the objective
  - Process selection and process optimization
  - Updating of a simulation study
  - Performance prediction

- Case History Applications
  - Shengli Field – China
    - Integrated static model
    - Integrated dynamic model
    - History matching
    - Oil recovery scenarios
  - Cactus Field - Mexico
    - Role of geology in static reservoir model building
    - PVT and fluid property characteristics
    - Integrated reservoir model
    - History matching
    - IOR/EOR evaluations
  - Chicontepec Basin Field – Mexico
    - Geology of turbidite depositional systems
    - Sand connectivity analysis and modeling
    - Fluid injection studies
    - Water injection pilot description
    - Simulation model components
    - History matching intricacies
    - Waterflood recovery performance prediction
    - EOS model for CO2 and gas injection
    - Simulation modeling of CO2-EOR and CO2-WAG injection
    - Enhanced miscibility for CO2-EOR
  - KMZ Field, Heavy Oil Fractured Reservoirs– Mexico
    - Field background and geology
    - Analysis of compartmentalization
    - Selection of a compartmentalized sector for EOR
    - Development of a refined simulation sector model
    - CO2 and N2 injection simulations
    - Identification of EOR application scenario for the field
  - An Unconventional Shale Gas Reservoir
Day 4

10. RESERVOIR SIMULATION HANDS-ON TUTORIALS
   - CMG-Package Software Installations on Participants computers
   - Introduction to CMG-Software Suit
     - IMEX, GEM, STARS, BUILDER, CMOST, RESULTS (2D, 3D GRAPH)
   - Static Geological Model Exercise
     - Creating using BUILDER
       - Initiating CMG-Luncher
       - Importing geological counter map of top structure
       - Loading isopach map
       - Importing petrophysical property maps (porosity, permeability, NTG,…)
       - Importing well trajectories
       - Importing well completion data
     - Importing from another platform (Petrel, Gocad,..)
       - Rescue file
       - Visualization
   - Dynamic Simulation Model Exercise
     - Creating using BUILDER
       - Preparing/formating historical production data
       - Importing/defining SCAL data (kr and pc)
       - Inputting PVT data (black oil example)
       - Model initialization
       - Exporting model properties
   - Three-phase Black Oil Simulation Exercise
     - CMG-IMEX, with BUILDER, RESULTS (2D, 3D GRAPH)
     - History matching
     - Performance prediction
     - Studying phase appearance and disappearance type situations
   - Three-phase Black oil Waterflood Simulation Exercise
     - CMG-IMEX, with BUILDER, RESULTS (2D, 3D GRAPH)
     - Conducting a pattern study
     - Setting injection and production wells
     - Simulating performance behavior

Day 5

11. RESERVOIR SIMULATION Hands-on TUTORIALS (continue)
   - Compositional Simulation, Carbon Dioxide Injection Exercise
     - CMG-GEM, with BUILDER, RESULTS (2D, 3D GRAPH)
     - Inputting EOS (for PVT)
     - Data entry and modifications of input data file of IMEX
     - History matching and comparing with black oil IMEX history match results
     - Studying Performance of CO2
- Compositional Simulation, Gas Condensate Exercise
  - CMG-GEM, with BUILDER, RESULTS (2D, 3D GRAPH)
  - Data file for a condensate reservoir
  - Studying the liquid saturation build up around a well block

- Thermal Simulation, Steam Injection Exercise
  - CMG-STARS, with BUILDER, RESULTS (2D, 3D GRAPH)
  - Inputting K-values (for PVT)
  - Data entry for steam injection and input data file modifications
  - Heavy oil reservoir steam injection application study

- Building PVT Properties Exercise
  - Introduction to Winprop
  - Fluid composition data set entry
  - Black oil PVT generation for IMEX
  - Compositional EOS generation for GEM
  - K-value generation for STARS

- Hydraulically Fractured Shale Reservoir Simulation Exercise
  - CMG-GEM, with BUILDER, IMEX, WINPROP, RESULTS (2D, 3D GRAPH)
  - Data entry for hydraulically fractured reservoirs
  - Discrete fracture representation versus stimulated reservoir volume representation