Al-Ayen University

College of Petroleum Engineering

Numerical Methods and Reservoir Simulation

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Lecture 2: Key Steps in a Simulation Study (Part 2)

Key Steps in a Simulation Study

1. Clear Objectives
2. Reservoir Characterization
3. **Model Selection**
4. Model Construction
5. Model Validation
6. Predictions
7. Documentation

Compare & Adjust

Model (Simulator) Selection

Aspects of Model

1. **Process**
2. Dimensionality
3. Approach

Model (Simulator) Selection

Determine the Process

1. **The Black Oil Model**

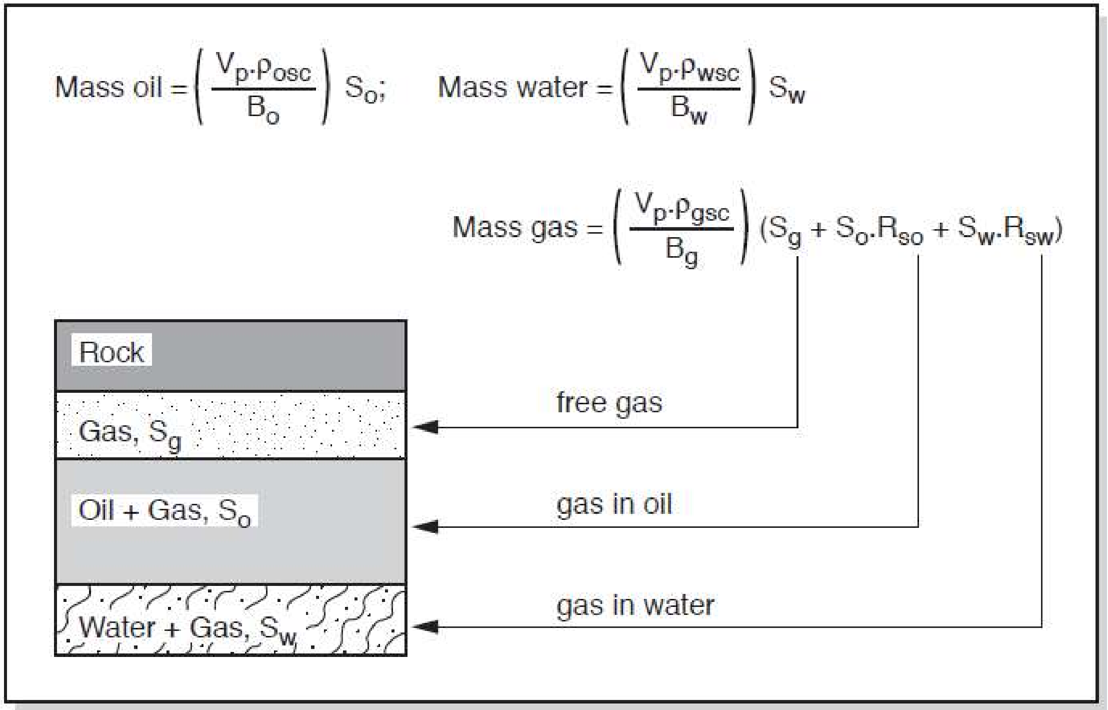
2. **More Complex Reservoir Simulation Models:**

   - **The Compositional Model**
   - **The Chemical Flood Model**
   - **Thermal Models**
   - **Dual-Porosity Models of Fractured Systems**
   - **Coupled Hydraulic, Thermal Fracturing and Fluid Flow Models**

Model (Simulator) Selection

The Black Oil Model:

It treats the three phases - ***oil, gas and water*** - as if they were ***mass components*** where ***only the gas is allowed to dissolve in the oil and water***. This gas solubility is described in oil and water by the gas solubility factors (or solution gas-oil ratios), Rso and Rsw, respectively.



Schematic of a grid block in a black oil simulator

Model (Simulator) Selection

The Black Oil Model:

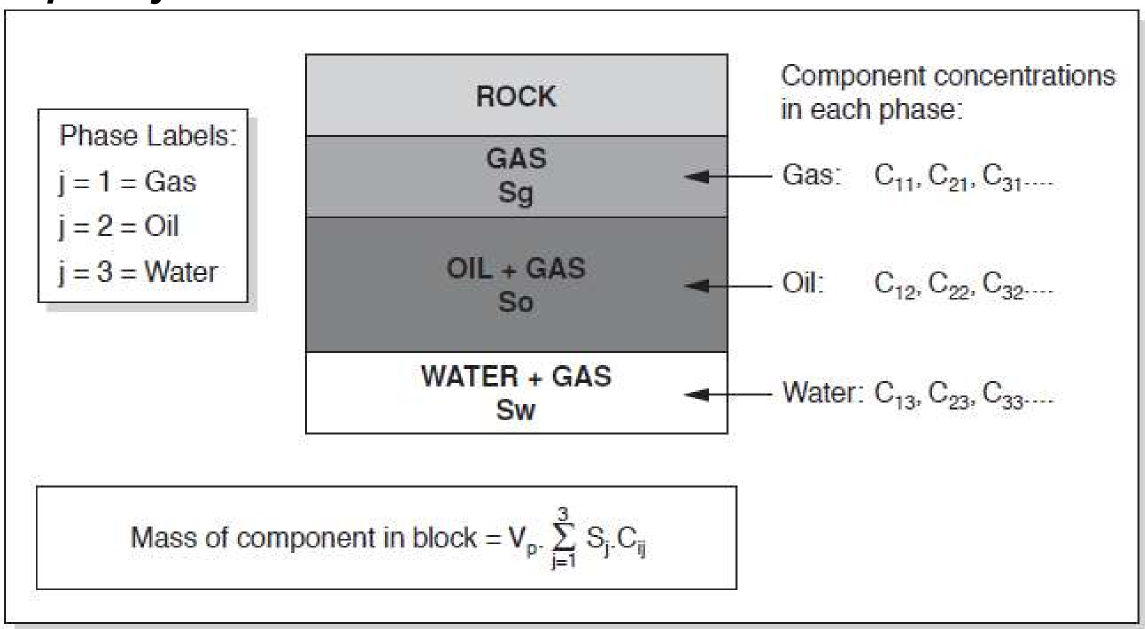
Reservoir processes that can be modelled using the black oil model include:

- Recovery by fluid expansion - solution gas drive (primary depletion).
- Waterflooding including viscous, capillary and gravity forces (secondary recovery).
- Immiscible gas injection.
- Some three phase recovery processes such as immiscible water-alternating- gas (WAG).
- Capillary imbibition processes.

Model (Simulator) Selection

The Compositional Model:

A compositional reservoir simulation model is required when ***significant inter-phase mass transfer effects occur*** in the fluid displacement process. This model usually defines three phases (again ***gas, oil and water***) but the ***actual compositions of the oil and gas phases are explicitly acknowledged*** due to their more complicated PVT behaviour. That is, the separate ***components (C1, C2, C3, etc.) in the oil and gas phases are explicitly tracked***.



The view of phases and components taken in compositional simulation. Cij - is the mass concentration of component i in phase j (j = gas, oil or water)

Model (Simulator) Selection

The Compositional Model:

Examples of reservoir processes that can be modelled using a compositional model include:

- Gas injection with oil mobilisation by first contact or developed (multi-contact) miscibility (e.g. in CO_2 flooding).
- The modelling of gas injection into near critical reservoirs.
- Gas recycling processes in condensate reservoirs.

Model (Simulator) Selection

The Chemical Flood Model:

- **This model has been developed primarily to model polymer and surfactant (or combined) displacement processes.**
- **Polymer flooding can be considered mainly as extended waterflooding with some additional effects in the aqueous phase which must be modelling e.g. polymer component transport, the viscosification of the aqueous phase, polymer adsorption, permeability reduction etc.**
- **Surfactant, flooding however, involves strong phase behaviour effects where third phases may appear which contain oil/water/surfactant emulsions.**
- **Extended chemical flood models are also used to model foam flooding.**

Model (Simulator) Selection

The Chemical Flood Model:

Examples of reservoir processes that can be modelled using a chemical flood model include:

- **Polymer flooding** which can be thought of as an “enhanced waterflood” to improve the mobility ratio and hence improve the microscopic sweep efficiency and also to reduce streaking in highly heterogeneous layered systems;
- **Polymer/surfactant flooding** where the main purpose of the surfactant is to lower interfacial tension (IFT) between the oil and water phases and hence to “release” or “mobilise” trapped residual oil; the polymer is for mobility control behind the surfactant slug;
- **Low-tension polymer flooding (LTPF)** where a more viscous polymer containing injected solution also contains some surfactant to reduce IFT; the combined effect of the lower IFT and viscous drive fluid improves the sweep and also helps to mobilise some of the residual oil;
- **Alkali flooding** where a solution of sodium hydroxide is injected into the formation. The sodium hydroxide may react with certain conponents in the oil to produce natural "soaps" which lower IFT and which may help to mobilise some of the residual oil;

Model (Simulator) Selection

The Chemical Flood Model:

Examples of reservoir processes that can be modelled using a chemical flood model include:

- **Foam flooding** where a surfactant is added during gas injection to form a foam which has a high effective viscosity (lower mobility) in the formation than the gas alone which may then displace oil more efficiently.
- Another near-wellbore process that can be modelled using such simulators in water shut-off using either polymer-crosslinked gels or so-called “relative permeability modifiers”.

Model (Simulator) Selection

Thermal Models:

- **In all thermal models heat is added to the reservoir either by injecting steam or by actually combusting the oil (by air injection, for example).**

- **The purpose of this is generally to reduce the viscosity of a heavy oil which may have μ_o of order 100s or 1000s of cP.**

- **The heat may be supplied to the reservoir by injected steam produced using a steam generator on the surface or downhole.**

- **Alternatively, an actual combustion process may be initiated in the reservoir - in-situ combustion - where part of the oil is burned to produce heat and combustion gases that help to drive the (unburned) oil from the system.**

Model (Simulator) Selection

Thermal Models:

Examples of reservoir processes that can be modelled using thermal models include:

- **Steam "soaks"** where steam is injected into the formation, the well is shut in for a time to allow heat dissipation into the oil and then the well is back produced to obtain the mobilised oil (because of lower viscosity). This is known as a **"*Huff n' Puff*"** process**.**

- **Steam "drive"** where the steam is injected continuously into the formation from an injector to the producer. Again, the objective is to lower oil viscosity by the penetration of the heat front deep into the reservoir.

- **In situ combustion** where - as noted above - an actual combustion process is initiated in the reservoir by injecting oxygen or air. Part of the oil is burned (oxidised) to produce heat and combustion gases that help to drive the (unburned) oil from the system. This is not a common improved oil recovery method but a number of field cases showing at least *technical success have been reported in the SPE literature.*

Model (Simulator) Selection

Dual-Porosity Models of Fractured Systems:

- These models have been designed explicitly to simulate multiphase flow in fractured systems where the oil mainly flows in fractures but is stored mainly in the rock matrix.
- Such models attempt to model the fracture flows (and sometimes the matrix flows) and the exchange of fluids between the fractures and the rock matrix.
- The models have been applied to model recovery processes in massively fractured carbonate reservoir such as those found in many parts of the Middle East and elsewhere in the world.
- There is quite considerable field experience of modelling such systems in certain companies but there are also doubts over the validity of such models to model flow in fractured systems.

Model (Simulator) Selection

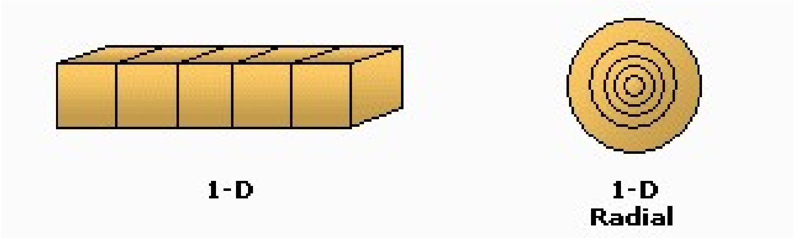
Aspects of Model

1. Process
2. **Dimensionality**
3. Approach

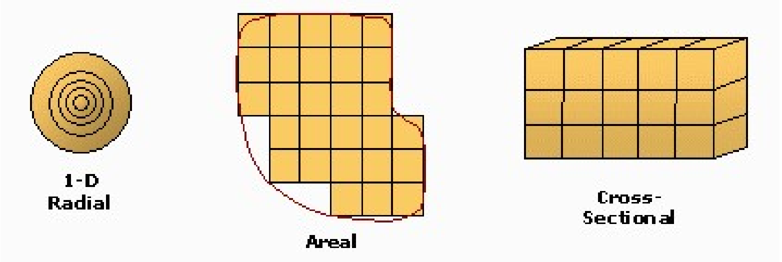
Model (Simulator) Selection

Determine the Dimensionality

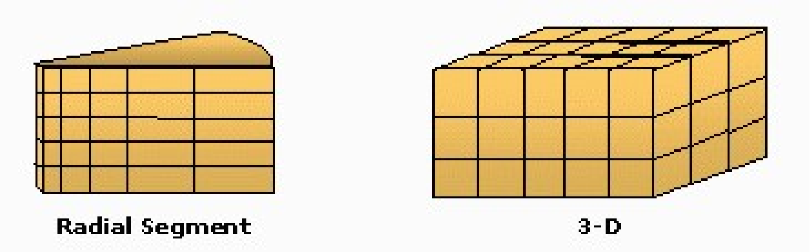
- Use 1D models for linear or radial flow in only one direction



- Use 2D models for linear or radial flow in two directions: Radial, areal, cross-sectional



- Use 3D models for situations for linear or radial flow in three directions: Pattern element, segment, fullfield



Model (Simulator) Selection

Aspects of Model

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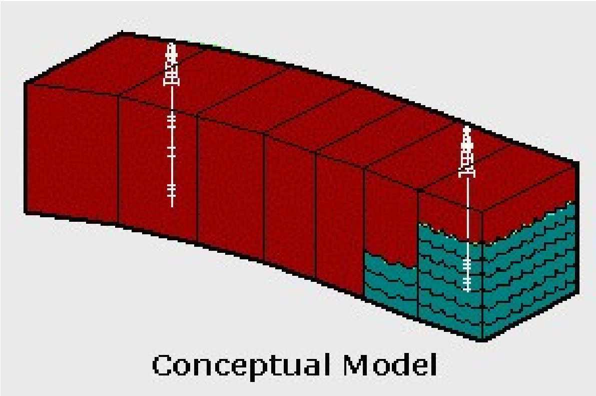
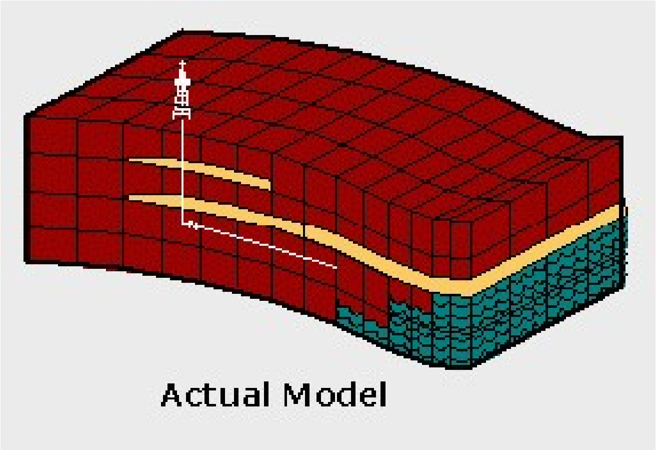
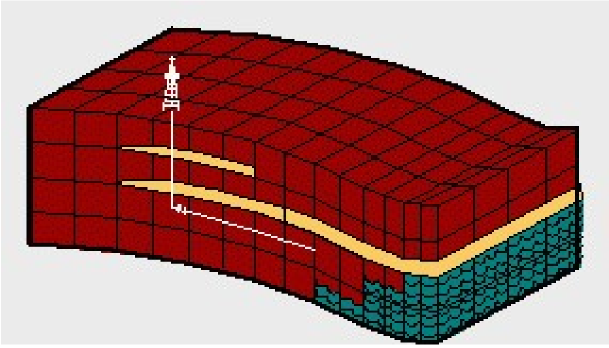
Model (Simulator) Selection

Determine the Approach





Detailed Geologic Description (May be matched to historic performance)



Higher Uncertainty Properties (Model depends on correlations and assumed data)

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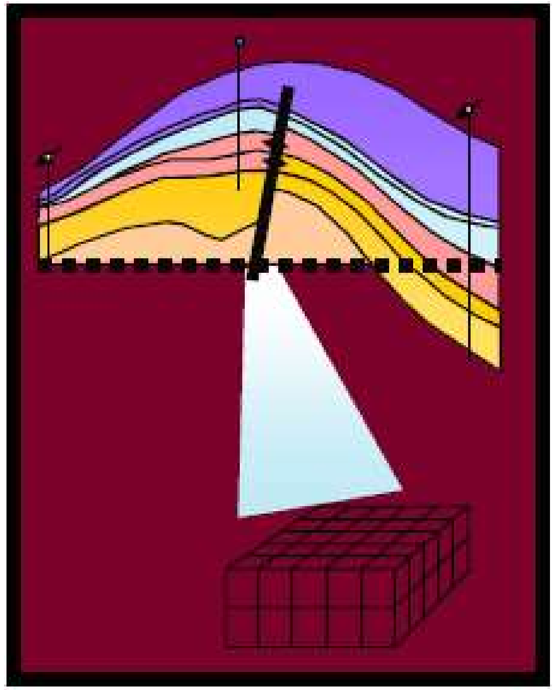
Model Construction

Converting the Geologic Model into a Simulation Model

1. Quality Control (QC) the geologic model for errors and problems
2. Scale-up the geologic model
3. Output the geologic model in simulation format
4. Output fault information for simulation
5. Output well data for simulation
6. Output production data in simulation formats and link to wells



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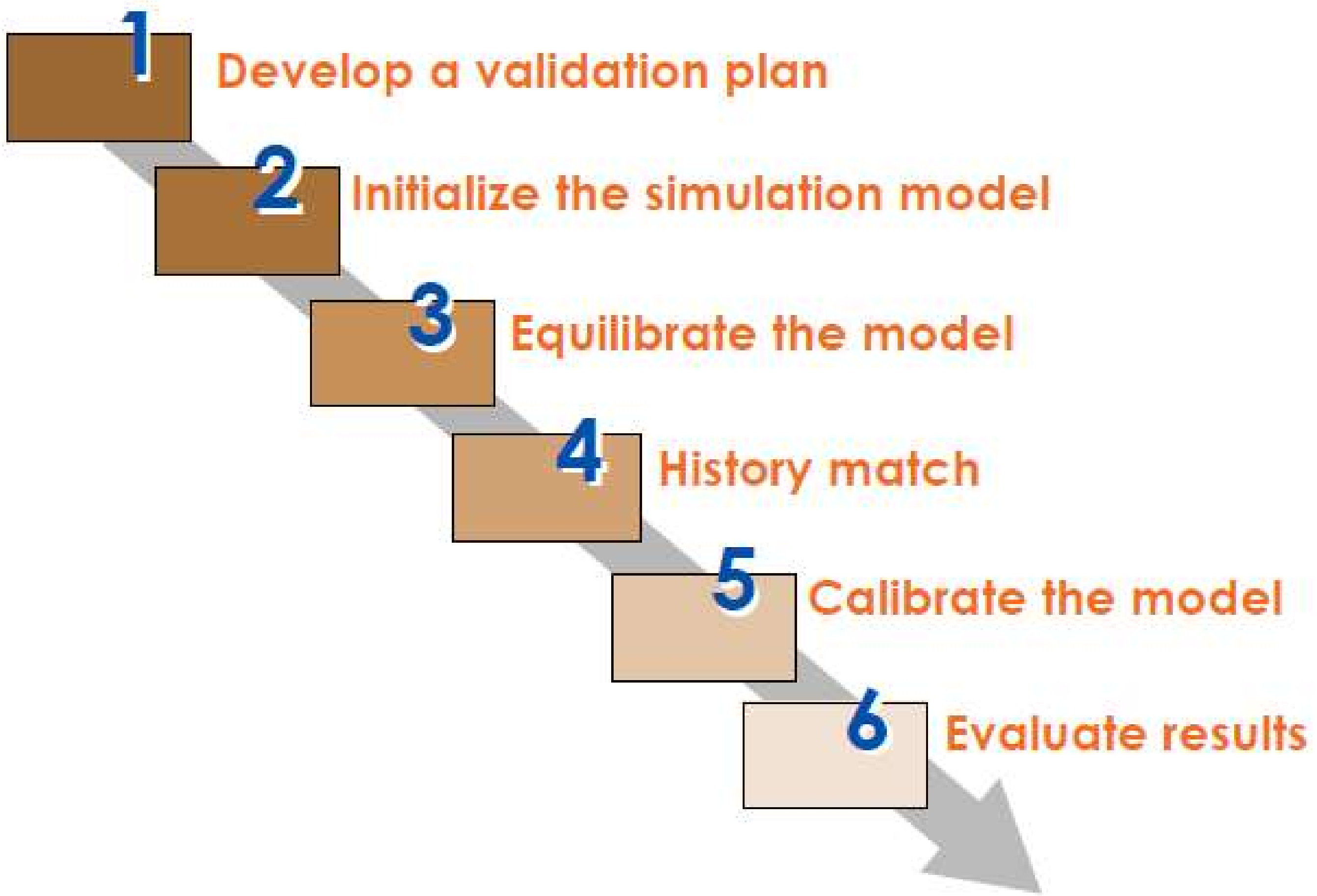
Model Validation



Model Validation

Two important ideas for the proper validation of reservoir models:

- History Matching must not be achieved at the expense of parameter modifications that are physically and/or geologically wrong
- Even when a model is fully validated, simulation results will still have some degree of uncertainty

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Predictions

Important considerations when making reservoir model predictions:

- Prediction cases shouldn't exceed capabilities of the model.
- Predictions need to be consistent with field practices.
- Simulation yields a non-unique solution with inherent uncertainties from:
  - Lack of validation (e.g., reservoirs with sparse geologic or engineering data).
  - Modeling or mathematical constraints because of compromises made in model selection.
  - Inherent uncertainties in reservoir characterization and/or scale– up to model dimensions.

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Documentation

Methods to document studies

- **Technical memorandum**
- **Formal report**
- **Presentation**
- **Store data files**
- **Share lessons learned with future project teams**

THANK YOU