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Reservoir Simulation - Lecture No02

Objectives:

- What is Reservoir Simulation and why is it needed?
- What are the application of Reservoir Simulation
- How Reservoir Simulation can help to Manage Oil and Gas Reservoirs?

Introduction

Reservoir simulation in the oil industry has become the standard for solving reservoir engineering problems. Simulators for various recovery processes have been developed and continue to be developed for new oil recovery processes. ***Reservoir simulation is the art of combining physics, mathematics, reservoir engineering, and computer programming to develop a tool for predicting hydrocarbon reservoir performance under various operating strategies***. There major steps involved in the development of a reservoir simulator: **formulation, discretization, well representation, linearization, solution, and validation**. *Formulation: outlines the basic assumptions inherent to the simulator, states these assumptions in precise mathematical terms, and applies them to a control volume in the reservoir*. The result of this step is a set of coupled, nonlinear partial differential equations (PDEs) that describes fluid flow through porous media. The PDEs derived during the formulation step, if solved analytically, would give reservoir pressure, fluid saturations, and well flow rates as continuous functions of space and time. Because of the highly nonlinear nature of the PDEs, however, analytical techniques cannot be used, and solutions must be obtained with numerical methods. In contrast to analytical solutions, numerical solutions give the values of pressure and fluid saturations only at discrete points in the reservoir and at discrete times. *Discretization: is the process of converting PDEs into algebraic equations*. Several numerical methods can be used to discretize the PDEs; however, the most common approach in the oil industry today is the finite difference method. The most commonly used finite-difference approach essentially builds on Taylor series expansion and neglects terms that are considered to be small when small difference in space parameters is considered. This expanded form is a set of algebraic equations. Finite element method, on the other hand,uses various functions to express variables in the governing equation. These functions lead to the development of an error function that is minimised in order to generate solutions to the governing equation. To carry out discretization, a PDEis written for a given point in space at a given time level. The choice of time level (oldtime level, current time level, intermediate timelevel) leads to the explicit, implicit, or Crank-Nicolson formulation method. The discretization process results in a system of nonlinear algebraic equations. These equations generally cannot be solved with linear equation solvers, and the *linearization of such equations becomes a necessary step before solutions can be obtained*. Well representation: is used to incorporate fluid production and injection into the nonlinear algebraic equations. *Linearization: involves approximating nonlinear terms (transmissibilities, production and injection, and coefficients of unknowns in the accumulation terms) in both space and time*. Linearization results in a set of linear algebraic equations. Any one of several linear *equation solvers can then be used to obtain the solution, which comprises pressure and fluid saturation distributions in the reservoir and well flow rates*. Validation: *of a reservoir simulator is the last step in developing a simulator, after which the simulator can be used for practical field* *applications. The validation step is necessary to make sure that no errors were introduced in the various steps of development or in computer programming*. This validation is distinct from the concept of conducting experiments in support of a mathematical model.

Validation of a reservoir simulator merely involves testing the numerical code.

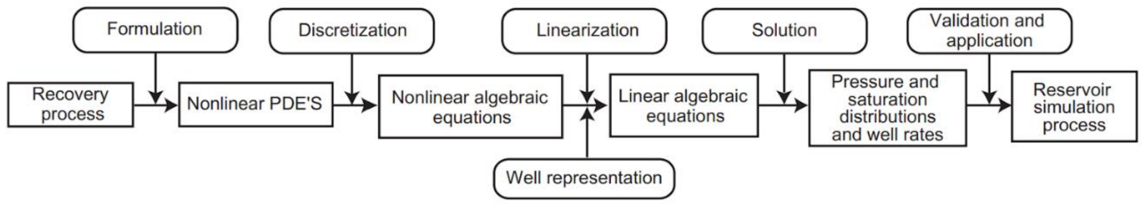

Figure 1: Major steps used to develop reservoir simulator *(modified from Odeh, A.S., 1982. An overview of mathematical modelling of the behaviour of hydrocarbon reservoirs. SIAM Rev. 24(3), 263.*).

Milestones for the engineering approach

The foundations for the engineering approach have been overlooked all these years. Traditionally, reservoir simulators were developed by first using a control volume (or elementary volume), such as that shown in below figure 2 for 1-D flow or in figure 3 for 3-D flow that was visualized by mathematicians to develop fluid flow equations. Note that point x in 1-D and point (x, y, z) in 3-D fall on the edge of control volumes. The resulting flow equations are in the form of PDEs. Once the PDEs were derived, early pioneers of simulation looked to mathematicians to provide solution methods. These methods started with the description of the reservoir as a collection of gridblocks, represented by points that fall within them (or grid points representing blocks that surround them), followed by the replacement of the PDEs and boundary conditions by algebraic equations, and finally the solution of the resulting algebraic equations. Developers of simulators were all the time occupied by finding the solution and, perhaps, forgot that they were solving an engineering problem. The engineering approach can be realised should one try to relate the terms in the discretized flow equations for any block to the block itself and to all its neighboring blocks.

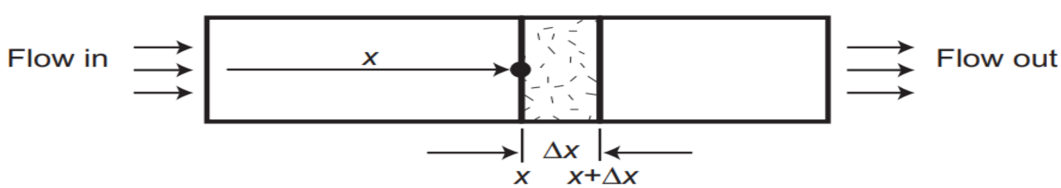

Figure 2: Control volume used by mathematicians for 1-D flow.

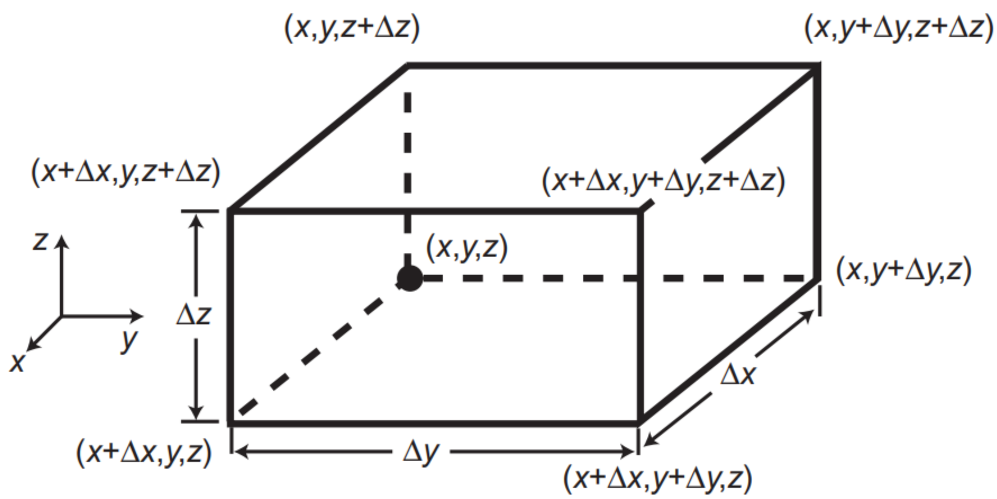

Figure 3: Control volume used by mathematicians for 3-D flow.

There were observations that the flow terms in the discretized form of governing equations were nothing but Darcy's law describing volumetric flow rate between any two neighbouring blocks. Making use of this observation coupled with an assumption related to the time level at which flow terms are evaluated, he developed the forward-central-difference equation and the backward-central-difference equation without going through the rigour of the mathematical approach in teaching reservoir simulation to undergraduate students. Control volume represented by a point at its centre in the mathematical approach as shown in Figure 4 for 1-D flow and Figure 5 for 3-D flow. This control volume is closer to engineer's thinking of representing blocks in reservoirs.

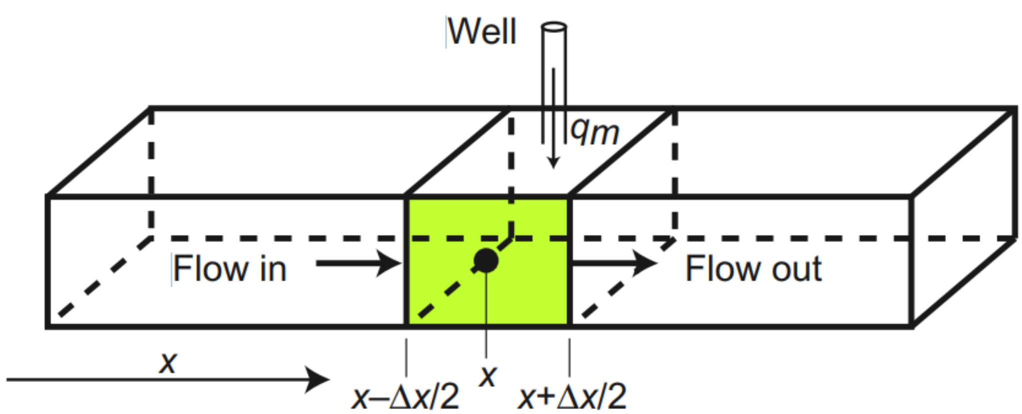

Figure 4: Control volume for 1-D flow.

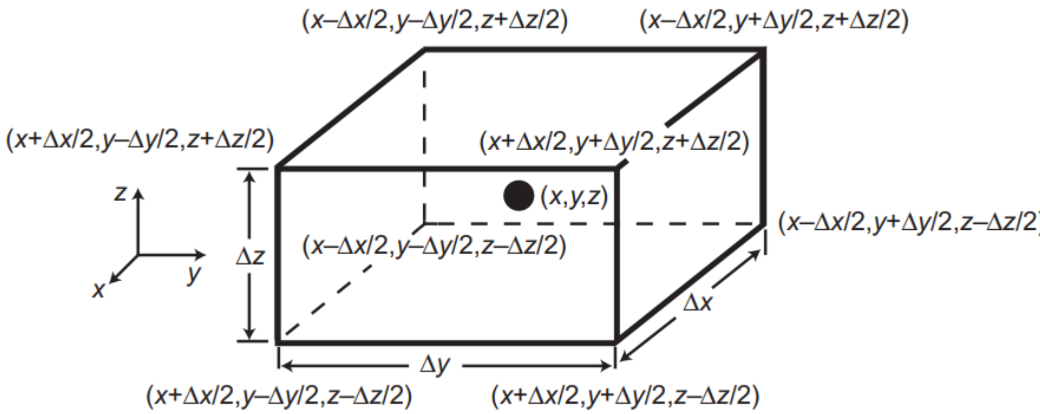

Figure 5: Control volume for 3-D flow.

Reservoir Simulation in simple words:

- As most of the reservoirs are not homogenous, reservoir simulation plays an important role to mimic the real situation. For example, if we want to calculate the flow rate using Darcy law, we will divide the reservoir into different blocks and the permeability value is different from one place to another within the blocks. So to calculate the flow as per Darcy we will take the length of the block and pressure difference; however if we calculate as one block, we will make some errors because we do not know which permeability value should be considered. That way we divided the reservoir into different blocks. Then we build the model based on each cell/block properties.

- Another example to consider in the reservoir simulation is the size of the reservoir. For example if we deal with a 2 km square in size reservoir and we are calculating centminers of blocks we are distributing the results into the whole reservoir. For instance, plotting time vs. pressure over time as the calculated values using mathematical equations must be matched with the real values taken from the field (history matching).

- Any reservoir simulation starts with building a model using geological information using contouring maps as a top surface then we put the logs information to build the subsurface model. Then we put the flow status in the reservoir using the well information in 2D and 3D figures. So to understand the variations in the pressures, permeability, porosity, saturation we need to solve it numerically using differential equations.
- The reservoir simulation is always close to reality but not 100 real. For example, pressure vs time measured in reality is slightly different from the numerical model. So subtracting pressure taken from the field and pressure taken from the numerical model is the difference between them and it is close to reality.
- Reservoir simulation includes different components including:
    - Numerical Model
    - Mathematical Model

    - Computer Model
    - Geometric Model
- The Geometric Model defines the shape, dimensions and status and layer distribution.
  Mathematical and numerical models using differential equations to solve the problems
  Computer model is a programmed simulators using all above equations
- Main objectives of reservoir simulation
  1- To build a model of the reservoir and to examine its performance in terms of production and pressure
  2- To predict future performance.
  3- To find ways to increase ultimate recovery hydrocarbons more economically
- Methodology of Reservoir Simulation
  1- The reservoir is divided into a number of blocks (or grid blocks)
  2- Basic geological and reservoir data is provided for each block
  3- Wells are positioned within the arrangement of blocks
  4- The target rate and well pressure are specific as a function of time
  5- The appropriate equations derived from Darcy's Law are solved to give the pressure and saturation of each block as well as production and injection for each well.

Using the seismic and well logs information we can identify the horizons which have the same characterisitcs then divide them into blocks for all wells. Each block has its own properties so the simulation will distribute the properties into the whole reservoir.

- Elements of a Reservoir Simulation Study
  1- Setting up study
  2- Defining the study’s objectives
  3- Formulating a model
  4- Data preparation
  5- Collecting rock and fluid data
  6- Reservoir description
  7- Collect well performance and completion data
  8- Defining producing conditions
  9- History matching
  10- Adjusting reservoir parameters to match past performance
  11- Predicting performance
  12- Running the simulator and analysing the outcome
  12- Sensitivity analysis
  13- Identify critical parameters
  14- Evaluation alternative strategies for development