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The Real Challenges in Reservoir Simulation

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Abstract

Reservoir simulation study is one of the keys to predict the future performance of a reservoir. It is the standard tool for solving reservoir engineering problems. The development of any petroleum field is a very complicated and risky project due to the involvement of different sources of mysteries and uncertainties on reservoir management. The understanding of mystery and uncertainty and the connection between these two form the core of a decision making process. Uncertainties related to geologic and fluid models play an important role. The mysteries related to the development of theories/laws are the key to reaching close to the real phenomena. So, uncertainties and mysteries are directly involved with reservoir simulation. This study outlines the inherent mysteries of reservoir simulation and the involvement of uncertainty related to the reservoir engineering/management activities which are needed to be addressed by the academicians, researchers, industry and developer of simulators. Some issues are discussed to enhance in-depth understanding of the real challenges. Proper addressing of the new models eliminates spurious assumptions in order to move toward the direction of knowledge dimension. The analysis of real challenges will open a new dimension of research ideas in reservoir engineering and simulation study. This study will help developing a scheme for an in-depth analysis of the reservoir before taking any decision of developing a simulator.

Introduction

In this current technological era, almost all phases of reservoir engineering problems are solved by reservoir simulators. It ranges from a simple decision through well testing to prediction of enhanced oil recovery. For every application, there is a separate user friendly and custom-designed simulator. Every simulation study is a unique process, starting from the reservoir description to the final analysis of the results. Reservoir simulation is the art of combining science (i.e., physics, chemistry, etc), mathematics, reservoir engineering, and computer programming to develop a tool for predicting hydrocarbon reservoir performance under various operating strategies. The first step of simulation is to develop a model equation which should be the true representation of the real scenario of the problem. Most of the cases, it is observed that the model equation is not the true representation of the natural phenomena due to the consideration of the spurious assumptions and some built-in limitations of the conventional mathematical equations. In contrary, some researchers only focus on how to increase the computational speed, CPU time etc. to develop efficient simulator without even realizing these assumptions. Also there are other immense challenges that lay behind the formulation of the model. Due to the build-in shortcomings of the current practices, recently the entire reservoir simulation process is facing serious disagreements. Unfortunately, almost all the existing simulators and their mathematical models are based on the conventional approach. It is also well-known that this approach comprises inherent assumptions which result the linearization of the model and erroneous solution.

Recently, Hossain and Islam (2010) explained a new approach, namely 'knowledge-based' approach where they considered adding the knowledge dimension to the problem. They showed that reservoir simulation equations have embedded variability and multiple solutions that are in line with physics rather than spurious mathematical solutions. With this clear addition of knowledge in reservoir simulation, a fresh perspective in this area is needed to be presented. Unlike the majority of reservoir simulation approaches available today, the 'knowledge-based' approach does not stop at questioning the fundamentals of reservoir simulation but offers solutions and demonstrates that proper reservoir simulation should be transparent and empower decision makers rather than creating a black box. In this regard, Hossain (2012) pointed out that engineering approach is the proper analytical method to empowering the planner decision because it does not create any black box simulator any more due to its inherent strength in formulation. The author also mentioned that as mathematical developments of new governing equations based on in-depth understanding of the above factors, these equations influence fluid flow in porous media under different flow conditions which is again the strength of engineering approach. Behavior of flow through matrix and fractured systems in the same reservoir, heterogeneity and rock/fluid properties interactions, Darcy and non-Darcy flow, and variable rock/fluid properties are among the issues that are thoroughly needed to be addressed during the development of a commercial simulator. The present research addresses those mysterious and unrealistic considerations of the conventional simulation approach. The comprehensive modeling of complex petroleum phenomena will help researcher and industry to rethink and revisit their contribution in reservoir simulation. It will also help to build a new rigorous simulator using the noble concept.

Challenges Need to be Tackled in Reservoir Simulation

In any branch of knowledge that deals with nature science, it is difficult to capture the natural phenomena and its performance over time due to its chaotic behavior. Sometime it is not possible to explain the features of the reality due to the highly nonlinear and chaotic behavior of the natural process. Reservoir behavior in underground is not a different case except the true presentation of natural phenomena. Most of the cases, researchers tried to linearize the natural and chaotic behavior through spurious assumptions. As an example, conventional approach considers Darcy's law as the constitutive equation. So, it is worth mentioning that the researchers need to address the core issues and the existing nature of reservoir simulation that lead to conclude the spurious and uncertain results. In this information age where computational capacity has remarkably increased, it is not a real challenge to eliminate the limitations of conventional methodology. Researchers have been trying to eliminate or modify the spurious assumptions by the most recently developed mathematical and computational tools (Hossain and Islam (2010).

In the same line of approach, the first step is to identify the most inherent shortcomings of the existing development features toward the reservoir simulator. Odeh (1982) is probably the researcher who initiated and depicted the major steps involved in the development of a reservoir simulator. To characterize the reservoir simulator, this approach is developed using the major steps such as formulation, discretization, well representation, linearization, solution, and validation. In the conventional simulation approach (Fig. 1), the algebraic flow equations are derived in three consecutive steps:

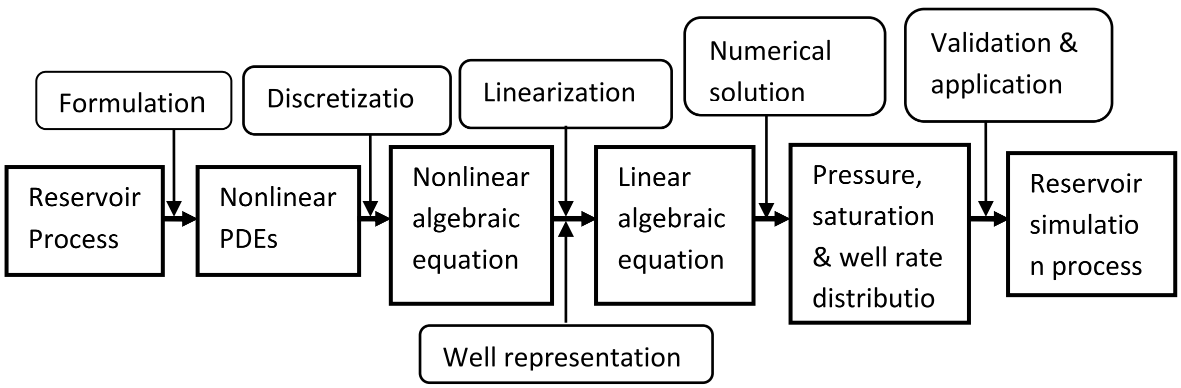

Figure 1. Major steps in conventional reservoir simulators (redrawn from Hossain, 2012)

i) derivation of the partial differential equations (PDEs) describing fluid flow in reservoir using the three basic principles (mass conservation, equation of state, constitutive equations), ii) discretization of reservoir into gridblocks or gridpoints, and iii) discretization of the resulting PDE in space and time (Abou-Kassem, 2008). The formulation step outlines the basic assumptions inherent to the simulator. These assumptions in its precise mathematical terms apply to a control volume in the reservoir (Fig. 1). Therefore, the researcher need to pay their attention trying to eliminate the above mentioned challenges as the first step toward the development of a true reservoir simulator.

Further, Newton's approximation is used to render these control volume equations into a set of coupled, nonlinear PDEs that describe fluid flow through porous media (Ertekin et al. 2001). These PDEs are then discretized, giving rise to a set of non-linear algebraic equations. Taylor series expansion is used to discretize the governing PDEs. The PDEs that are 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, 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. To carry out discretization, a PDE is written for a given point in space at a given time level. The choice of time level 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 linearization of such equations becomes a necessary step before solutions can be obtained. Well representation is used to incorporate fluid production/injection into the nonlinear algebraic equations. Linearization involves approximating nonlinear terms in both space and time. Linearization results in a set of linear algebraic equations. Any of the several linear equation solvers can then be used to obtain the solution. The solution comprises of 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 error was introduced in the various steps of development and in computer programming. Unfortunately, all the steps have its own limitations due to the build-in spurious assumptions.

Uncertainty and Mystery Cloud in the Simulation

The whole petroleum industry is like a reservoir of risk and uncertainty. It is true that the investors, planners, and executives are in a situation where they do not feel secure to invest their capital investment in the petroleum industry. It is due to the probability of success rate of 8 – 12% in any exploration activity (Hossain et al., 2010). The unstable energy pricing is the other factor which mitigates the decision of the investor. Almost all the uncertainty and risk are directly or indirectly related to the reservoir simulation. Therefore, it is important to identify the big challenges and uncertainty cloud of petroleum industry. Recently, Hossain et al., (2010) demonstrated the chronological steps and major sources of uncertainty and risks of the whole petroleum industry ranging from exploration through production to end user. This article addresses some of the fundamental challenges, assumptions and uncertainty and mystery behind the mathematics and approaches that are used in modeling of reservoir. Interested researchers can visit the references of Hossain and Islam (2010), Hossain et al., (2010), and Hossain (2012).

Future Guideline to Meet the Research Challenges

The recent results and successes reported by Mousavizadegan et al. (2007), Hossain el al., (2008), Mousavizadegan et al. (2008), Mustafiz et al. (2008a, 2008b), Hossain and Islam (2009), and Hossain el al., (2009) in solving equations without linearization promise the success of the above mentioned simulation challenges. The most important aspect eliminating the spurious assumptions and consideration of the appropriate methodology is that it leaves the open choice of multiple solutions, generating a set of cloud points rather than single point solution. In addition, a more accurate range of predicted values will reduce the uncertainty to a great extent. The benefits of the research are three-fold. If the results show significant differences between the solutions of the linearized and non-linearized models, the stage will be set to seriously consider the development of new approach in reservoir simulation and the generated cloud of solutions creates an upper and lower bounds for the solution that help decision makers in risk analysis. If, however, the results show insignificant differences for a given range of parametric values, then the proposed research will confirm the appropriateness of linearization of model equations for the given range and, therefore, delineates the range for which fine tuning of the current techniques is necessary.

Conclusions

In this study, a critical review is made on conventional practice in the petroleum industry. The current misconceptions and inherent assumptions are addressed that are directly or indirectly related to reservoir simulation. The real challenges of the reservoir simulation that need to be addressed are outlined here. Proposals are made to overcome a number of challenges encountered during modeling of petroleum reservoirs based on current practices in the field of reservoir simulation. It is shown that eliminating at least some of the misconceptions would be significantly different for most of the solution regime by quoting the references. This finding would help to determine more accurate range of risk factors in petroleum reservoir management. The new era of reservoir simulator will open a door for describing the natural phenomena in a better way and understanding.

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