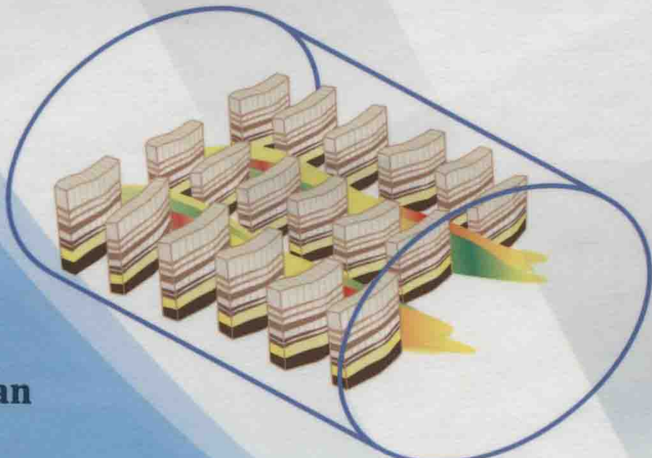
ADVANCED PETROLEUM RESERVOIR SIMULATION



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Foreword

Petroleum is still the world's most important source of energy and reservoir performance and petroleum recovery are often based on assumptions that bear little relationship to reality. Not all equations written on paper are correct and are only dependent on the assumptions used. In reservoir simulation, the principle of *garbage in and garbage out* is well known leading to systematic and large errors in the assessment of reservoir performance. This book presents the shortcomings and assumptions of previous methods. It then outlines the need for a new mathematical approach that eliminates most of the shortcomings and spurious assumptions of the conventional approach. The volume will provide the working engineer or graduate student with a new, more accurate, and more efficient model for a very important aspect of petroleum engineering: reservoir simulation leading to prediction of reservoir behavior.

Reservoir simulation studies are very subjective and vary from simulator to simulator. Currently available simulators only address a very limited range of solutions for a particular reservoir engineering problem. While benchmarking has helped accept differences in predicting petroleum reservoir performance, there has been no scientific explanation behind the variability that has puzzled scientists and engineers. For a modeling process to be accurate, the input data have to be accurate for the simulation results to be acceptable. The requirements are that various sources of errors must be recognized and data integrity must be preserved.

Reservoir simulation equations have an embedded variability and multiple solutions that are in line with physics rather than spurious mathematical solutions. To this end, the authors introduce mathematical developments of new governing equations based on in-depth understanding of the factors that influence fluid flow in porous media under different flow conditions leading to a series of workable mathematical and numerical techniques are also presented that allow one to achieve this objective.

This book provides a readable and workable text to counteract the errors of the past and provides the reader with an extremely useful predictive tool for reservoir development.

Dr. James G. Speight

Introduction

Petroleum is still the world's most important source of energy, and, with all of the global concerns over climate change, environmental standards, cheap gasoline, and other factors, petroleum itself has become a hotly debated topic. This book does not seek to cast aspersions, debate politics, or take any political stance. Rather, the purpose of this volume is to provide the working engineer or graduate student with a new, more accurate, and more efficient model for a very important aspect of petroleum engineering: reservoir simulation.

The term, "knowledge-based," is used throughout as a term for our unique approach, which is very different from past approaches and which we hope will be a very useful and eye-opening tool for engineers in the field. We do not intend to denigrate other methods, nor do we suggest by our term that other methods do not involve "knowledge." Rather, this is simply the term we use for our approach, and we hope that we have proven that it is more accurate and more efficient than approaches used in the past.

It is well known that reservoir simulation studies are very subjective and vary from simulator to simulator. While SPE benchmarking has helped accept differences in predicting petroleum reservoir performance, there has been no scientific explanation behind the variability that has frustrated many policy makers and operations managers and puzzled scientists and engineers. In this book, for the first time, reservoir simulation equations are shown to have embedded variability and multiple solutions that are in line with physics rather than spurious mathematical solutions. With this clear description, a fresh perspective in reservoir simulation is presented.

Unlike the majority of reservoir simulation approaches available today, the "knowledge-based" approach in this book 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. Mathematical developments of new governing equations based on in-depth understanding of the factors that influence fluid flow in porous media under different flow conditions are introduced. The behavior of flow through matrix and fractured systems in the same reservoir, heterogeneity and fluid/rock properties interactions, Darcy and non-Darcy flow are among the issues that are thoroughly addressed. For the first time, the fluid memory factor is introduced with a functional form. The resulting governing equations are solved without linearization at any stage. A series of clearly superior mathematical and numerical techniques are also presented that allow one to achieve this objective.

In our approach, we present mathematical solutions that provide a basis for systematic tracking of multiple solutions that are inherent to non-linear governing equations. This is possible because the new technique is capable of solving non-linear equations without linearization. To promote the new models, a presentation of the common criterion and procedure of reservoir simulators currently in use is provided. The models are applied to difficult scenarios, such as in the presence of viscous fingering, and results are compared with experimental data. It is demonstrated that the currently available simulators only address a very limited range of solutions for a particular reservoir engineering problem. Examples are provided to show how our approach extends the currently known solutions and provides one with an extremely useful predictive tool for risk assessment.

The Need for a Knowledge-Based Approach

In reservoir simulation, the principle of GIGO (Garbage in and garbage out) is well known (latest citation by Rose, 2000). This principle implies that the input data have to be accurate for the simulation results to be acceptable. The petroleum industry has established itself as the pioneer of subsurface data collection (Abou-Kassem et al, 2006). Historically, no other discipline has taken so much care in making sure input data are as accurate as the latest technology would allow. The recent plethora of technologies dealing with subsurface mapping, real time monitoring, and high speed data transfer is evidence of the fact that input data in reservoir simulation are not the weak link of reservoir modeling.

However, for a modeling process to be knowledge-based, it must fulfill two criteria, namely, the source has to be true (or real) and the subsequent processing has to be true (Zatzman and Islam, 2007). The source is not a problem in the petroleum industry, as a great deal of advances have been made on data collection techniques. The potential problem lies within the processing of data. For the process to be knowledge-based, the following logical steps have to be taken:

- Collection of data with constant improvement of the data acquisition technique. The data set to be collected is dictated by the objective function, which is an integral part of the decision-making process. Decision making, however, should not take place without the abstraction process. The connection between objective function and data needs constant refinement. This area of research is one of the biggest strengths of the petroleum industry, particularly in the information age.
- The gathered data should be transformed into information so that it becomes useful. With today's technology, the amount of raw data is so huge, the need for a filter is more important than ever before. It is important, however, to select a filter that doesn't skew the data set toward a certain decision. Mathematically, these filters have to be non-linearized (Mustafiz et al, 2008). While the concept of non-linear filtering is not new, the existence of non-linearized models is only beginning to be recognized (Abou-Kassem et al, 2006).
- Information should be further processed into "knowledge" that is free from preconceived ideas or a "preferred decision." Scientifically, this process must be free from information lobbying, environmental activism, and other biases. Most current models include these factors as an integral part of the decision-making process (Eisenack et al, 2007), whereas a scientific knowledge model must be free from those interferences as they distort the abstraction process and inherently prejudice the decision-making. Knowledge gathering essentially puts information into the big picture.

For this picture to be free from distortion, it must be free from non-scientific maneuvering.

- Final decision-making is knowledge-based, only if the abstraction from the above three steps has been followed without interference. Final decision is a matter of Yes or No (or True or False or 1 or 0) and this decision will be either knowledge-based or prejudice-based. Figure i.1 shows the essence of knowledge-based decision-making.

The process of aphenomenal or prejudice-based decision-making is illustrated by the inverted triangle, proceeding from the top down (Fig. i.2). The inverted representation stresses the inherent instability and unsustainability of the model. The source data from which a decision eventually emerges already incorporates their own justifications, which are then massaged by layers of opacity and disinformation.

The disinformation referred to here is what results when information is presented or recapitulated in the service of unstated or unacknowledged ulterior intentions (Zatzman and Islam, 2007). The *methods* of this disinformation achieve their effect by presenting evidence or raw data selectively, without disclosing either the fact of such selection or the criteria guiding the selection. This process of selection obscures any distinctions between the data coming from nature or from any all-natural pathway, on the one hand, and data from unverified or untested observations on the other. In social science, such maneuvering has been well known, but the recognition of this aphenomenal (unreal) model is new in science and engineering (Shapiro et al, 2007).

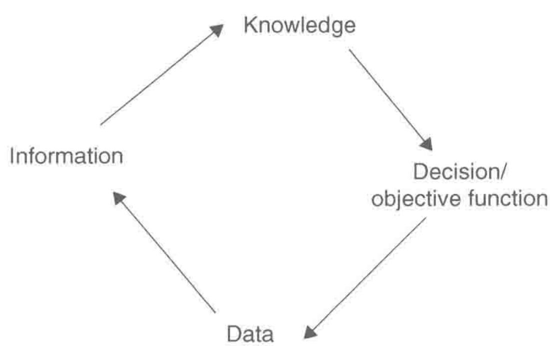

Figure i.1 The knowledge model and the direction of abstraction.

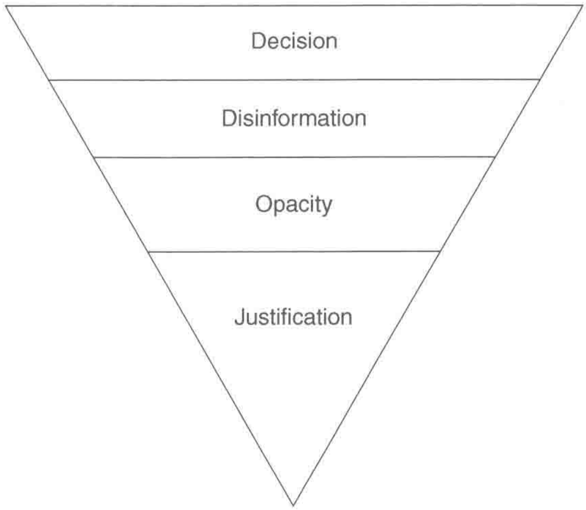

Figure i.2 Aphenomenal decision-making.

Summary of Chapters

Chapter 1 presents the background of reservoir simulation, as it has been developed in the last five decades. This chapter also presents the shortcomings and assumptions of previous methods. It then outlines the need for a new mathematical approach that eliminates most of the short-comings and spurious assumptions of the conventional approach.

Chapter 2 presents the requirements for data input in reservoir simulation. It highlights various sources of errors in handling such data. It also presents guidelines for preserving data integrity with recommendations for data processing.

Chapter 3 presents the solutions to some of the most difficult problems in reservoir simulation. It gives examples of solutions without linearization and elucidates how the knowledge-based approach eliminates the possibility of coming across spurious solutions that are common in the conventional approach. It highlights the advantage of solving governing equations without linearization and demarks the degree of errors committed through linearization, as done in the conventional approach.

Chapter 4 presents a complete formulation of black oil simulation for both isothermal and non-isothermal cases, using the engineering approach. It demonstrates the simplicity and clarity of the engineering approach.

Chapter 5 presents a complete formulation of compositional simulation, using the engineering approach. It shows how very complex and long governing equations are amenable to solutions without linearization using the knowledge-based approach.

Chapter 6 presents a comprehensive formulation of the material balance equation (MBE) using the memory concept. Solutions of the selected problems are also offered in order to demonstrate the need of recasting the governing equations using fluid memory. This chapter shows how a significant error can be committed in terms of reserve calculation and reservoir behavior prediction if the comprehensive formulation is not used.

Chapter 7 uses the example of miscible displacement as an effort to model enhanced oil recovery (EOR). A new solution technique is presented and its superiority in handling the problem of viscous fingering is discussed.

Chapter 8 highlights the future needs of the knowledge-based approach. A new combined mass and energy balance formulation is presented. With the new formulation, various natural phenomena related to petroleum operations are modeled. It is shown that with this formulation one would be able to determine the true cause of global warming, which in turn would help develop sustainable petroleum technologies. Finally, this chapter shows how the criterion (trigger) is affected by the knowledge-based approach. This caps the argument that the knowledge-based approach is crucial for decision-making.

Chapter 9 concludes major findings and recommendations of this book.

The Appendix is the manual for the 3D, 3-phase reservoir simulation program. This program is available for download from **www.scrivenerpublishing.com**.

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