Fundamentals of SUSTAINABLE DRILLING ENGINEERING

M. E. Hossain
A. A. Al-Mejed

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Phillip Carmical (pcarmical@scrivenerpublishing.com)

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M. Enamul Hossain, PhD

Abdulaziz Abdullah Al-Majed, PhD

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Dedicated with love to the blessed soul of the first author's

Late mother, Azizun Nesa (1951 – 1981)
Late grandmother, Hazera Khatun (1922 – 1992)

whose devotion and affection never ceases and whose beautiful memories are ever lasting.

and

dedicated to the second author's wife and children for their understanding and support.

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Foreword

Albert Einstein famously said, "I was originally supposed to become an engineer but the thought of having to expend my creative energy on things that make practical everyday life even more refined, with a loathsome capital gain as the goal, was unbearable to me." Engineers are faced with solving problems that few dare approaching. They do so for a "loathsome capital gain" yet they remain responsible for making things practical and efficient. Drilling into a formation that is thousands of meters underground is a daunting task. To make that process sustainable is nothing short of a miracle. Promises of such miracles are an act of a magician unless backed by a solid scientific foundation. This book addresses a problem that only a few years ago was deemed to be an impossible task, and it does so with a solid scientific foundation, yet with utmost clarity.

Engineering is an art that needs conscious participation and skillful mentoring. The best way to learn how to handle an engineering problem is to sit down next to a friendly, patient, experienced practitioner and work through problems together, step-by-step. This book will give the readers similar learning experience. The chapters are organized in a very logical fashion. The book is easy to understand even though it is a product of extensive research in fundamentals of drilling engineering and is enhanced with new knowledge and the most up-to-date information. Such a hands-on approach cannot be found in any other textbook in engineering. This textbook promotes the concept of true paradigm shift in the topic of drilling engineering that remains one of the most complex yet least understood subjects of the modern era.

It is no secret that no single current drilling engineering book is adequate in explaining natural phenomena. When it comes to challenging tasks, such as environmental sustainability, the inadequacy becomes even more pronounced and has caused tremendous frustration in the current energy management schemes. While everyone seems to have a solution, it is increasingly becoming clear that these options are not moving our environment to any cleaner state. Few have ventured into proposing a solution that would question the foundation of conventional thinking. This book takes that necessary step and offers something that can only be characterized as groundbreaking. This textbook offers some of the advanced and recent achievements related to drilling operations in addition to fundamentals of different drilling areas and sustainable operations. It breaks out of conventional practices of using prior knowledge as a basis. It takes a bold step of going to the root of

the current practices and challenges in the area. By doing so, this textbook creates a true knowledge for undergraduate students to strengthen their basics of drilling engineering and researchers who need guidelines for further improvement in the area. One application is the use of basics of drilling engineering along with more workout examples and exercises at the end of each chapter. This book puts forward a guideline how to handle the inherent complexity of recent challenges that are being faced by the industry. Many people feel the petroleum industry has not been as good as others in propagating sustainable activities for enterprise applications. Even researchers simplify and often marginalize the inherent complexity of drilling operations, especially the drilling fluid properties toward sustainability considering assumptions in an unjustified way. As the technology becomes more capable and sophisticated, it becomes more important to understand how to use it well. This unique book is a valuable step in advancing that understanding. In my view, this book is a must for any student, practicing engineer, expert, researcher, and academic who aspires to understand the complex process involved in drilling engineering.

Professor M. R. Islam
Former Killam Chair in Petroleum Engineering, Dalhousie University, Canada
President, Emertec Research and Development Ltd., Halifax, NS, Canada

Preface

Sustainable Drilling Engineering? I have heard sustainable used in conjunction with "green" energy sources such as wind or solar. I have heard sustainable with respect to agriculture. But using sustainable with respect to drilling? Isn't that an oxymoron such as "jumbo shrimp" or "accurate rumors?" Doesn't drilling have to do with oil and gas, a finite resource?

Yes, it does. But it is more than that. Drilling is the process of accessing resources below the surface of a planet such as Earth. These resources include oil and gas, naturally. But consider one of the most critical resources mankind needs: water. In many places, the only source of that precious resource is underground. How about various minerals? Gold and silver come to mind; but more important to us are iron, aluminum, and the many rare earths needed by our electronic devices. The initial discovery of these resources is often at the end of a drill bit. How about geothermal energy? That is a potential source of energy that is limitless, and it takes a borehole drilled into the ground to access it. How about learning science? We study the geology of the Earth. We look at the past climates with ice cores in Antarctica. We determine the flow of contaminates underground. We look for life on other worlds. Drilling is not only for oil and gas; it is needed for any access to the natural resources and knowledge found below the surface of our (or any other) planet.

Sustainable means to be able to be maintained at a certain rate or level or to be upheld or defended. In the case of this book, I consider both definitions to be an accurate description of the text. Drilling operations are expensive, time consuming, and potentially dangerous to people and the environment. One must maintain a high level of engineering and operational skill that mitigates any potential harm to anyone or anything. It is the drilling engineering and the process of drilling that is sustainable. Therefore, the title of this book is accurate. It is drilling engineering that is sustainable.

Drs. Hossain and Al-Majed have written a book on sustainable drilling engineering. In it, they describe the many aspects of the drilling engineer's practice. In some work I did with the United States' National Aeronautics and Space Administration some years ago, the Jet Propulsion Laboratory engineers and my Colorado School of Mines team reduced drilling wellbores into three categories: penetrate the rock, remove the rock, and keep the wellbore open. This book explains it all.

They start with an introduction to the profession of drilling engineering and the people that are involved in making drilling sustainable. The authors then go on to describe and explain the machinery of the drilling rig that enables people to drill wells. Towards the end

of the book, they discuss how to finish a well, called well completions and detail how to determine the economics of drilling and completing wellbores in a chapter on cost analysis.

You have to penetrate the rock. The authors launch into drill string design from the top drive/kelly through the drill pipe and bottom hole assembly to the drill bit. They explain how to choose the bit and operate the rig at peak capability. They also discuss in another chapter how to direct the wellbore trajectory in the process called directional drilling. This includes the process of horizontal drilling that is a remarkable process for opening up oil and gas resources that were never considered a resource just a decade ago.

You have to remove the rock. The authors describe drilling fluids and the hydraulics derived from their flow. They continue in logical sequence to well control issues and methods; and, on to the prediction processes not only for the source of well control problems, pore pressures; but also to the bane of well control, fracture gradients and the loss of fluids.

You have to support the borehole. One way to stop wellbores from collapsing or to control pressures is to run steel pipe. This is called casing and its design is the subject of a chapter in the book. This is followed by the filling of the ring shaped area (called the annulus) between the rock walls and the casing with cement, the most common way to prevent the migration of fluids from one formation to another. The casing and cement helps to maintain the borehole.

All of this knowledge goes into making drilling and the engineering required be sustainable. This book is the start in learning how to make drilling engineering sustainable.

Dr. Alfred William Eustes III, Ph.D., P.E.
Colorado School of Mines
Petroleum Engineering Department
Golden, Colorado 80401, USA

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Summary

Drilling Engineering is one of the oldest technologies on earth and the technological advancement in this area is well recognized by the scientists, engineers, researchers, and the petroleum industry. However, the hydrocarbon extraction industry is still unmoved by attempts of alternative energy sources to displace it as the primary source of energy for the foreseeable future. In this information era, the key to success in the drilling industry has been the results of utilization of technological advancement. Knowledge gaps have been created in drilling technologies because of the challenges that face the oil companies in the exploration for oil and gas in areas which is remote, deep and difficult to reach, whether on land or offshore areas. The scientific and technological advancement could not reduce the level of risks and data uncertainties in the drilling operations to the desired level since performing drilling operations in a sustainable fashion does not have the priority in an era of continuously increasing demand for oil and gas, and increasing costs of projects. Unfortunately, the petroleum industry is still perceived as one of the expensive branches of modern industries. To date there are very few textbooks that explain the sustainable drilling operations with fundamentals of drilling engineering. As the first and only complete guide for petroleum engineers on basic drilling engineering and a milestone book for environmentalist and researchers, this is a best choice to have for the drilling community. This textbook explains how the drilling technology can be operated in a sustainable fashion. However, the main focus is given on drilling fluid because lot more researches are needed to green the mud technology for a stainable drilling operation. The book also covers the fundamental issues for the beginners who are interested in learning drilling engineering. The textbook explains the concepts of the basic subject matter clearly and presents the existing knowledge ranges from history of drilling technology to well completion. The book presents the engineering terminologies in a clear manner so that the beginner of the drilling engineering would be able to understand the drilling concepts with minimum efforts. In addition, each chapter contains some workout examples and exercises for a comprehensive understanding of the subject. This will make the reader interested in reading the book. For the potential researchers, the book outlines related issues and covers gaps in knowledge. It also outlines how the industry can plan the rig operations in a sustainable manner. The book explains the concepts in a readable fashion very clearly. It includes all the basic aspects of drilling engineering including rig operations, drilling hydraulics, cementing jobs, drilling fluids, drillstring, bit and casing design, and horizontal and directional drilling. In addition, the book talks about the sustainable petroleum operations and points out topics that deserve further research. However, we believe that each chapter deserves to be a short

book and we tried to focus the most important concepts and main topics of the subject matter. The textbook is a foundation and resourceful guide, and an excellent resource for petroleum engineering students, drilling engineers, supervisors and managers, researchers, and environmental scientists. The specific topics of the drilling engineering that are covered in this book include the following chapters:

Chapter 1 – Introduction: This chapter introduces the fundamental features of the drilling. It discusses some of the core issues related to drilling engineering, activities need to be completed before starting drilling operations, etc. Finally, the concepts of sustainable drilling operations are introduced.

Chapter 2 – Drilling Methods: This chapter discusses all characteristics related to drilling rig and its components. The chapter focuses on the drilling methods used for hydrocarbon exploitation and covers the cable tool drilling rig, rotary drilling rig and its components, rotary rig systems, types of rigs, current advancement of rig systems, and the knowledge gap that needs to be filled in drilling.

Chapter 3 – Drilling Fluids: The chapter covers almost all the fundamental and basic ideas of mud engineering including an extensive literature survey on the drilling fluid. The chapter presents the current trend and the future challenges of the technology and also identifies where the R&D personals need to focus their attention toward the sustainable mud engineering.

Chapter 4 – Drilling Hydraulics: Drilling hydraulics plays an essential role while drilling activities continue to operate. To understand and properly design the hydraulic system, it is important to discuss hydrostatic pressure, types of fluid flow, criteria for type of flow, and types of fluids commonly used in the various operations at the drilling industry. In addition, it covers the type of fluids; pressure losses in the surface connections, pipes, annulus, and the bit; jet bit nozzle size selection; surge pressures due to vertical pipe movement; optimization of bit hydraulics, and carrying capacity of drilling fluid. The current and future trends of the hydraulic system are also discussed in the last sections of the chapter.

Chapter 5 – Well Control and Monitoring Program: The chapter discusses well control and monitoring system in general. It covers how a well can be controlled in a sequential and safe way in addition to its different control devices used in any well control and monitoring system. This chapter covers the whole range of real-time monitoring system and discusses the current practices in the industry and the future trend of the well control and monitoring system in general.

Chapter 6 – Formation Pore and Fractures Pressure Estimation: This chapter deals with the formation fluid pressure and fracture pressure, understanding of the variation of these two parameters with depth, and rock mechanical properties including geological aspects of rock mechanics. The development of underground stresses and the related formation pressure, fracture pressure are also outlined in this chapter. The different causes of abnormal pressure with detailed detection and prediction techniques are the main focus of the chapter. Finally, the current state-of-the-art on formation pore pressure and fracture pressure along with the fracture gradient are elaborated in this chapter.

Chapter 7 – Basics of Drillstring Design: The chapter covers the basic drillstring and bottom-hole assembly (BHA) design including drill bit. The different types of drill bit and their applications are outlined in detail. The ROP optimization and the factors that influence the ROP are discussed and the existing ROP models are explained. The current

development in the area and the future trend of drill string and BHA are also presented in the chapter.

Chapter 8 – Casing Design: This chapter focuses the types of casing, different components of casing and landing procedures including the manufacturing of casing, rig side operations, handling procedure, casing design, and selection criteria. Finally, the current practice and the future trend of the casing for the oil industry are discussed.

Chapter 9 – Cementing: This chapter discusses how the well cementing plays a vital role by providing the different functions throughout the life of a well. It explains the cement slurry design process which covers the parameters those affect the cementing process during and after placement of cement slurry in the annulus. The chapter also discusses lab testing and the rheological properties of cement slurry. The current developments and future challenges faced by oil well cementing industry are outlined at the end of the chapter.

Chapter 10 – Horizontal and Directional Drilling: This important chapter discusses the fundamental concepts related to horizontal and directional drilling including well survey, other forms of directional drilling technologies such as horizontal wells, extended reach wells, multilateral wells, slim hole drilling, and coiled tubing drilling. Future trends in directional drilling are also discussed on a separate subsection in addition to the current trend of the directional drilling technology.

Chapter 11 – Well Drilling Costs Analysis: This chapter focuses the factors affecting the drilling costs, types of costs, and variables that influence the well drilling costs. Some typical examples are set to enhance the drilling costs estimation. The purpose of the chapter is to review the primary methods used to assess drilling cost and complexity. The foundational basis of each approach is described and a critical assessment of model assumptions is provided.

Chapter 12 – Well Completion: This chapter addresses the needs for well completion and focuses on building the current foundation of engineers on completion techniques. It further provides practical exercises and industrial applications on the key decisions needed to be made during the completion processes. In addition, an in-depth discussion on the emerging technologies and methodologies on well completion is covered. The current trend and practices of the well completion along with its future trend are also identified in the chapter.

Dr. M. Enamul Hossain
and
Dr. Abdulaziz Al-Majed