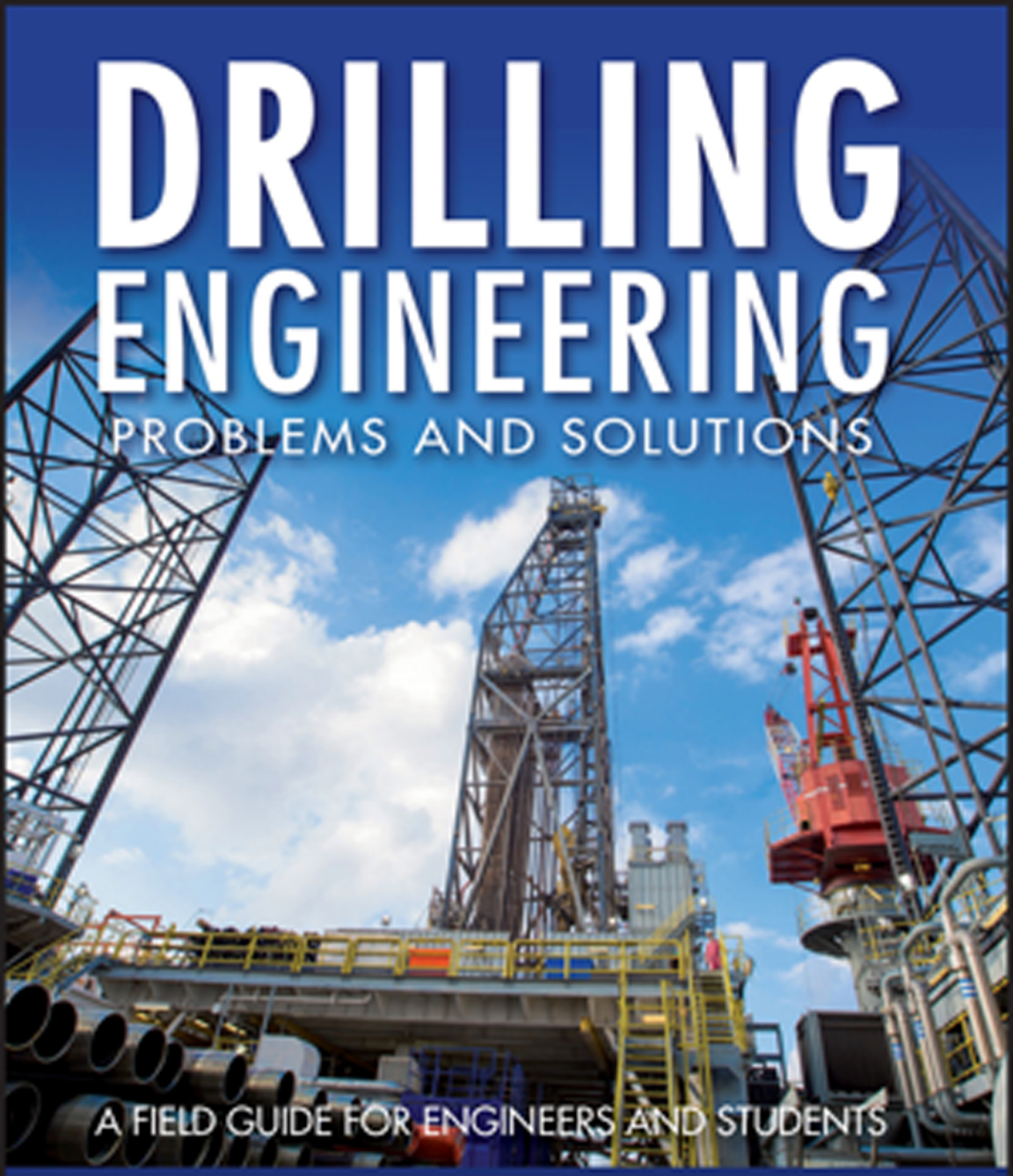
DRILLING ENGINEERING

PROBLEMS AND SOLUTIONS



A FIELD GUIDE FOR ENGINEERS AND STUDENTS

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To first author's mother, the late Azizun Nesa and uncle the late Mohammad Ismail

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Foreword

With recent awareness of environmental sustainability, it has become clear that most of our technological advances are in fact a quick fix of problems that arose from practices that shouldn't have been commenced to begin with. At the risk of being labeled an anarchist, it is only proper to say, this fear has been shared by some of the most non-controversial engineers and scientists (Nobel Laureate Chemist, Robert Curl, for instance). In this era of technological advancement being later labelled as 'technological disaster', drilling technologies bring in a silver lining. The advancements made in drilling technologies have been phenomenal and marks one of the proudest moments of the petroleum industry. Unfortunately, whenever disasters strike, the blame game begins and everyone rushes to disavow modern technology. With the spectacular failure in Deep water horizon project in 2010, many questioned the validity of modern drilling advances, particularly in the areas of offshore drilling. Lost in that hysteria was the fact that research that fuelled the instant solutions sought during that fateful drilling operation was in fact flawed. After the dust settled, however, the tragic event established one fact: there has to be a Q&A type of problem solving book that addresses real-life drilling problems with well researched answers. This book is the first of its kind that addresses field problems and answers with solutions that can become a guide for avoiding such problems in future. The book doesn't compromise the relevance or scientific details in responding to hard hitting field problems. Rather than giving a technician's response or a quickfix, it gives a researcher's response with backing of field engineers with decades of experience. The book is a masterpiece that is helpful for practicing engineers as well as professors, who can better serve the discipline by introducing field problems that are solved with a combination of research and field experience.

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Introduction

1.0 Introduction of the Book

Albert Einstein famously stated, "Scientists investigate that which already is; engineers create that which has never been." It is no surprise that any engineering project begins with defining a problem. However, the degree and the magnitude of the problems vary due to the nature of an engineering endeavor. Petroleum resources are the lifeline of modern civilization and drilling operations form the most important component of the petroleum industry. As such, drilling engineering has numerous problems, solutions of which are challenging. Added to this complexity is the fact that drilling operations involve the subsurface – clearly out of our sight. In absence of direct evidence, the best a drilling engineer can do is to speculate based on existing geological data and experience of the region. As a result, planning of drilling and its implementation is one of the greatest challenges for planners, administrators, and field professionals. To complete an engineering project, the planning phase must have all possible problem scenarios, followed by projected solutions. This is because once the problem occurs, one doesn't have the time to figure out the solution impromptu. This book

is designed to help in solving likely problems encountered during drilling operations. Of course, the list of problems is not exhaustive but the science established in solving the problem is comprehensive, thereby allowing operators to draw upon personal experiences and use this book as a guideline. This chapter introduces the fundamental aspects of the drilling problems faced by the drilling operators, drillers, crews, and related professionals in general. It identifies the key areas in which drilling problems are encountered, along with their root causes.

1.1 Introduction of Drilling Engineering

Despite recent concerns about their sustainability, petroleum resources continue to be the lifeline of modern civilization. This role of oil and gas will continue in the foreseeable future. Petroleum production is inherently linked to drilling technology, ranging from exploration to production, from monitoring to remediation and environmental restoration. Nearly one-quarter of the petroleum industry's entire exploration and production budget is dedicated to drilling expenses. The complete cycle of petroleum operations includes seismic survey, exploration, field development, hydrocarbon production, refining, storage, transportation/distribution, marketing, and final utilization to the end user. The drilling technology has been developed through the efforts of many individuals, professionals, companies and organizations. This technology is a necessary step for petroleum exploration and production. Drilling is one of the oldest technologies in the world. *Drilling engineering is a branch of knowledge where the design, analysis and implementation procedure are completed to drill a well as sustainable as possible* (Hossain and Al-Majed, 2015). In a word, it is the technology used to unlock crude oil and natural gas reserves. The responsibilities of a drilling engineer are to facilitate the efficient penetration of the subsurface with wellbore and cementing operations that range from the surface to an optimum target depth, while minimizing safety and environmental hazards.

1.2 Importance of Drilling Engineering

It is well known that the petroleum industry drives the energy sector, which in turn drives modern civilization. It is not unlikely that every day human beings are getting the benefits out of the petroleum industry. The present modern civilization is based on energy and hydrocarbon resources. The growth of human civilization and necessities of livelihood over time

inspired human beings to bore a hole for different reasons (such as drinking water, agriculture, hydrocarbon extraction for lighting, power generation, to assemble different mechanical parts, etc.). Only a small fraction of petroleum resources is considered to be recoverable and an even tinier fraction of that is available on the surface, making underground resources virtually the only source of hydrocarbons. The flow of oil is ensured only through drilling engineering playing a pivotal role. Naturally, any improvement in drilling practices will bring multifold benefits to the energy sector and much more to the overall economy.

1.3 Application of Drilling Engineering

Throughout human civilization, drilling in numerous forms played a significant role. As such, the applications of drilling technology are numerous. The applications of drilling range from children's toys to modern drilling of a hole for the purpose of any scientific and technological usage. Humans have been using this technology for underground water withdrawal from ancient times. Drilling technology is a widely used expertise in the applied sciences and engineering such as manufacturing industries, pharmaceutical industries, aerospace, military defense, research laboratories, and any small-scale laboratory to a heavy industry, such as petroleum. Modern cities and urban areas use the drilling technology to get the underground water for drinking and household use. The underground water extraction by boring a hole is also used for agricultural irrigation purposes. Therefore, there is no specific field of application of this technology. It has been used for a widespread field based on its necessity. This book focuses only on drilling a hole with the hope of hydrocarbon discovery; therefore, here the drilling engineering application means a shaft-like tool (i.e., drilling rig) with two or more cutting edges (i.e., drill bit) for making holes toward the underground hydrocarbon formation through the earth layers especially by rotation. Hence the major application of drilling engineering is to discover and produce redundant hydrocarbon from a potential oil field.

1.4 Drilling Problems, Causes, and Solutions

The oil and gas industry is recognized as one of the most hazardous industries on earth. Extracting hydrocarbon from an underground reservoir is very risky and uncertain. Therefore, it is very important to find out the root causes of its risk and uncertainty. The majority of the risks and

uncertainties related to this business are encountered while drilling. As a result, drilling problems offer an excellent benchmark for other practices in petroleum engineering as well as other disciplines. However, the key to having a successful achievement of the drilling objectives is to design drilling programs based on anticipation of potential drilling problems. The more comprehensive the list of problems the more accurate the solution manual will become. The best modus operandi is to avoid running into a scenario where problems arise. This preventative style will lead to safer and more cost-effective drilling schemes. It is well understood that even one occurrence of the loss of human life, environmental disaster, or loss of rig side area can have a profound effect on the welfare of the entire petroleum industry. Some of the drilling problems comprise of drillpipe sticking, stuck pipe, drillstring failures, wellbore instabilities, hole deviation and well path control, mud contamination, kicks, hazardous and shallow gas release, lost circulation, formation damage, loss of equipment, personnel, and communications. There are some other problems specifically related to slim hole drilling, coiled tubing drilling, extended reach drilling, and under-balance drilling, etc. There is a famous saying, "*prevention is better than cure*". So, the motto should be "drill a hole safely without having any accident, incident, or harm to this planet, with minimum costs". The drilling operations should be in a sustainable fashion where the minimization of drilling problems and costs has to have the top priority.

1.5 Drilling Operations and its Problems

Globally, modern rotary oil well drilling has been continued for over a century. Although, drilling itself has been a technology known to mankind for millennia (going back to Ancient China and Egypt), the earliest known commercial oil well in the United States was drilled in Titusville, Pennsylvania, in 1857. Before this time, such innovations as 4-legged derrick, "jars", reverse circulation drilling, spring pole method, and other drilling accessory techniques had been patented. Drake's famed well itself was drilled with cable tool and reached only 69 ft below the surface – a distance far shallower than drilling feats achieved by water wells. Even though M. C. and C. E. Baker, two brothers from South Dakota, were drilling shallow water wells in unconsolidated formations of the Great Plains, it wasn't until the late 1800s that the Baker brothers were using rotary drilling in the Corsicana field of Navarro County, Texas. In 1901 Captain Anthony Lucas and Patillo Higgins applied it to their Spindletop well in Texas. By 1925, the rotary drilling method was improved with the use of a diesel engine.

In the meantime, soon after the Drake well, the Sweeney stone drill was patented in 1866. This invention had essential components of modern-day drilling, such as swivel head, rotary drive and roller bit. In terms of drilling bit, the most important discovery was the introduction of the diamond bit. This French invention of 1863 (although ancient Egyptians were known to use such drills in rock quarries) was put in practice to drill a 1,000 ft hole with a 9" diamond bit in 1876. In terms of drilling mud, the history of early oil wells indicates that natural drilling mud was used, with the addition of locally available clay. It is conceivable that early engineers learned the technique of drilling mud operations by observing the fact that as water collected in situ mud from the formation its ability to clean the wellbore increases. However, the use of mud was formalized by the U.S. Bureau of Mines in 1913, soon after which significant changes to mud chemistry were invoked. By the 1920s, natural clay was substituted in favor of barite, iron oxide, and mined bentonite clays. With the introduction of a commercial drilling mud company (NL Baroid), mud chemistry has evolved drastically to make access to deeper formations possible (Barrett, 2011). The next quantum leap would come in the 1970s when conventional drilling mud materials were deemed unsafe for the environment and new regulations were introduced. The tradition of environment-friendly drilling operations began.

Today's sophisticated techniques are allowing unreachable formations to extract hydrocarbon beyond vertical and direction wells. In the 1980s, the petroleum industry went through a revolution during which period horizontal well technology was introduced and perfected. At present, drilling companies can drill vertically, directionally, and horizontally using the available technologies with an unprecedented precision and speed. However, there are gaps in these quantum leaps and certain aspects of drilling remain improvised and in need of modernization. These areas have been skipped because the primary focus of the last few decades has been automation and control rather than overall effectiveness of the drilling operation. Once a drilling site is identified, a drilling team starts to make preparations of rig installation prior to drilling. During the whole process of drilling, there might be numerous problems such as technical, geological, geographical, manpower, management, financial, environmental, and political. This book is limited to a focus on technological, geological and environmental problems and their solutions.

1.5.1 Common Drilling Problems

Farouq Ali famously wrote, "It's easier to land a man on the moon than describing a petroleum reservoir" (JPT, 1970). Indeed, the petroleum industry is the

only one that doesn't have the luxury of 'field visit' or 'field inspection'. In the drilling industry, the most evident problem is the nature of the job itself. The obvious challenge is that we cannot see with our naked eyes what is really happening inside the subsurface. Even if we plan very carefully, it is almost certain that problems related to drilling operations will happen while drilling a well. Understanding and anticipating drilling problems, understanding their causes, and planning solutions are necessary for an overall well cost control which ensures successfully reaching the target zone.

The most prevalent drilling problems include pipe sticking, lost circulation, hole deviations and directional control, pipe failures, borehole instability, mud contamination, formation damage, annular hole cleaning, hazardous gas and shallow gas (i.e., H_2S-bearing formation and shallow gas), cave-in hole (collapse), bridging in wells, crookedness of wells/deflection of wells, mud cake formation, pollution and corrosion in wells, stacked tools, drillstring failures, kicks, slow drilling, formation damage, and equipment, communications and personnel-related problems. There are some specific problems related to directional drilling which cover directional/horizontal well drilling, multilateral well drilling, coiled tubing drilling, under-balanced drilling, slim hole drilling. To get the true benefits after knowing the real problems and their solutions, we have to know the answers to the following: i) what problems are to be expected, ii) how to recognize the problem signals, iii) what courses of action need to be taken to combat these problems quickly and economically, and iv) how to employ the learning from the experiences and best real-world solutions. The direct benefit of these answers will have an impact on reducing overall drilling cost, assurance of an economically successful hydrocarbon recovery, and improving the performance of the overall well construction.

1.6 Sustainable Solutions for Drilling Problems

Drilling is a necessary step for petroleum exploration and production. However, drilling into a formation that is thousands of meters underground with extremely complex lithology is a daunting task. The conventional rotary drilling technique falls short since it is costly and contaminates surrounding rock and water due to the use of toxic drilling fluids. The overall approach that includes the usage of toxic chemicals as determined in the 1970s continues to be in operation. In view of increased awareness of the environmental impact, efforts are being made for making drilling practices sustainable (Hossain and Al-Majid, 2015). To make the process sustainable and environmentally friendly, however, is an extremely challenging

task. It involves making fundamental changes in engineering practices that have been in place ever since the plastic revolution took place over a century ago. This is the most difficult challenge faced by the petroleum industry tasked with reducing environmental impact of petroleum operations. Recent advances in the petroleum industry have made it possible to have a drilling technique that meets both technical and environmental challenges. Such solutions were considered to be an impossible task only a decade ago. For example, sustainability is one of the prime requirements for greening the drilling fluid system. However, it is a challenge for us how to green the drilling fluid because it depends on the source/origin of the base materials, additives, technology used, and the process itself. Therefore, the development of a sustainable drilling operations and green fluid requires a thorough cost-effective investigation.

In this globalization era, technology is changing every day. Due to the continuous changes and competition between the organizations, it is becoming a challenge for saving this planet. As a result, in management, a sustainable organization can be defined as an organization where exist i) political and security drivers and constraints, ii) social, cultural and stakeholder drivers and constraints, iii) economic and financial drivers and constraints, and iv) ecological drivers and constraints. Thus sustainability concept is the vehicle for the near future Research & Development (R&D) for technology development. A sustainable technology will work towards natural process. In nature, all functions or techniques are inherently sustainable, efficient and functional for an unlimited time period (i.e. $\Delta t \rightarrow \infty$). By following the same path as the function inherent in nature, some recent research shows how to develop a sustainable technology (Appleton, 2006, Hossain *et al.*, 2010; Hossain, M.E., 2011; Hossain, M.E., 2013; Khan *et al.*, 2005; Khan and Islam, 2005; Khan 2006a and 2006b). The success of a high-risk hydrocarbon exploration and production depends on the use of appropriate technologies.

Generally, a technology is selected based on criteria, such as technical feasibility, cost effectiveness, regulatory requirements and environmental impacts. Khan and Islam (2006a) introduced a new approach in technology evaluation based on the novel sustainability criterion. In their study, they not only considered the environmental, economic and regulatory criteria, but investigated sustainability of technologies (Khan *et al.*, 2005; Khan and Islam, 2005; Khan 2006a and 2006b). "Sustainability" or "sustainable technology" has been used in many publications, company brochures, research reports and government documents which do not necessarily give a clear direction (Khan, 2006a; Appleton, 2006). Sometimes, these conventional approach/definitions mislead to achieve true sustainability.

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. Matters of research in fundamentals of drilling engineering, complete with knowledge and most up-to-date information are extremely useful in designing a sustainable drilling well design which ultimately help in reducing the drilling problems in general.

The lack of proper training in environmental sustainability has caused tremendous frustration in the current energy management sector. While everyone seems to have a solution, it is increasingly becoming clear that these options are not moving our environment to any cleaner state. This book offers some of the advanced and recent achievements related to drilling operation problems in addition to fundamentals of different drilling-related problems and sustainable operations. Relevant parameters, ranging from drilling fluid properties to rock heterogeneity will be discussed and methods presented to make the operation sustainable. Complexities arising from directional and horizontal wells in difficult-to-drill formations will be discussed in order to offer practical solutions for drilling problems.

1.7 Summary

This chapter discusses some of the core issues related to drilling engineering. Starting with the history of petroleum well drilling, the chapter introduces various topics of drilling engineering, as presented in this book Topics include, even before starting drilling operations, different types of drilling problems, and the concept of sustainable drilling operations.

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