

Fundamentals of SUSTAINABLE DRILLING ENGINEERING

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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.*

Contents

Foreword	xix
Preface	xxi
Acknowledgements	xxiii
Summary	xxv
1 Introduction	1
1.1 Introduction	1
1.2 Introduction of Drilling Engineering	1
1.3 Importance of Drilling Engineering	2
1.4 Application of Drilling Engineering	2
1.5 History of Oil Discovery	3
1.6 An Overview of Drilling Engineering	5
1.6.1 Licensing, Exploration and Development	5
1.6.2 Role of Drilling during Field Development	7
1.6.3 Types of Drilling Wells	7
1.6.4 Sequences of Drilling Operations	9
1.7 Organization Chart and Manpower Requirements during Drilling Operations	12
1.8 Aspect of Sustainability in Drilling Operations	13
1.9 Summary	15
References	16
2 Drilling Methods	17
2.1 Introduction	17
2.2 Types of Drilling Methods	18
2.2.1 Cable Tool Drilling	18
2.2.2 Rotary Drilling	19
2.3 Rotary Drilling Rig and its Components	20
2.4 Drilling Process	22
2.4.1 Power System	23
2.4.2 Hoisting System	28

2.4.3	Circulation System	40
2.4.4	Rotary System	49
2.5	Types of Rotary Drilling Rigs	50
2.6	Nature and Need for Sustainable Drilling Operations	57
2.7	Current Practice in the Industries	58
2.7.1	Derrick and Substructure	59
2.7.2	Hoisting System	59
2.7.3	Pressure Control System	61
2.8	Future Trend in Drilling Methods	61
2.9	Summary	62
2.10	Nomenclature	62
2.11	Exercise	63
	Appendix 2A	65
	Rig Floor (Conventional Rotary Rig)	65
	Rig Floor (Top Drive)	65
	Blowout Preventer Stack And Wellhead	66
	Drilling Fluid Equipment	66
	References	71
3	Drilling Fluids	73
3.1	Introduction	73
3.2	Drilling Fluid Circulating System	74
3.3	Classification of Drilling Fluids	76
3.3.1	Water-base Mud	77
3.3.2	Oil-based Mud	77
3.3.3	Air or Gas-base Mud	79
3.3.4	Foam	80
3.3.5	Special Types of Muds	80
3.4	Composition of Drilling Fluids	82
3.5	Mud Additives	84
3.5.1	Chemical Additives	84
3.5.2	Additives for Water-based Mud	85
3.5.3	Additives for Oil-based Mud	90
3.6	Measurement of Drilling Fluids Properties	101
3.6.1	Mud Density	102
3.6.2	Mud Viscosity	103
3.6.3	Gel Strength	112
3.6.4	pH Determination	113
3.6.5	Filtration Tests	115
3.6.6	Sand Content	117
3.6.7	Determination of Liquid and Solids Content	117
3.6.8	Alkalinity	119
3.6.9	Water Hardness	119

3.6.10	Water Analysis	120
3.6.11	Chemical Analysis	120
3.6.12	Chloride Concentration	121
3.6.13	Cation Exchange Capacity of Clays	121
3.6.14	Electrical Properties	123
3.7	New Drilling Mud Calculations	124
3.8	Design of Mud Weight	125
3.9	Current Developments in Drilling Fluids	128
3.9.1	Formulation of WBM	128
3.9.2	Formulation of OBM	129
3.9.3	Formulation of Gas-based Mud	129
3.9.4	Development of Environment-Friendly Mud System	130
3.9.5	Application of Nanotechnology	131
3.9.6	Application of Biomass	131
3.10	Future Trend on Drilling Fluids	131
3.10.1	Cost Analysis	131
3.10.2	Development of Environment Friendly Mud Additives	132
3.10.3	Sustainability	132
3.10.4	Development of Mud and/or Additives for HTHP Applications	133
3.11	Summary	133
3.12	Nomenclature	133
3.13	Exercises	135
	References	136
4	Drilling Hydraulics	141
4.1	Introduction	141
4.2	Types of Fluids	142
4.2.1	Newtonian Fluid	142
4.2.2	Non-Newtonian Fluid	143
4.3	Flow Regimes	156
4.3.1	Laminar Flow	156
4.3.2	Turbulent Flow	156
4.3.3	Transitional Flow	160
4.4	Hydrostatic Pressure Calculation	162
4.4.1	Liquid Columns	162
4.4.2	Gas Columns	166
4.5	Fluid Flow through Pipes	169
4.6	Fluid Flow through Drill Bits	171
4.7	Pressure Loss Calculation of the Rig System	173
4.7.1	Pipe Flow	174
4.7.2	Annular Flow	175
4.7.3	Bit Flow	176
4.7.4	Pump Calculations	182

4.8	Current Development on Drilling Hydraulics	183
4.8.1	Drilling Hydraulics Optimization	183
4.8.2	Down-hole Motor Technology	184
4.8.3	Drilling Hydraulics for the Aerated “Foam” Fluids	185
4.8.4	Drilling Hydraulics of Aerated fluids for Vertical Wells	188
4.8.5	Drilling Hydraulics of Aerated fluids for Deviated, Horizontal and ERD Wells	188
4.8.6	Drilling Hydraulics for Coiled Tubing Drilling	190
4.9	Future Trend on Drilling Hydraulics	192
4.9.1	Hydraulics of Dual Gradient Drilling	193
4.9.2	Enlargement of Hydraulics Operating Window	193
4.9.3	Introducing New Hole Cleaning Devices	194
4.10	Summary	195
4.11	Nomenclature	195
4.12	Exercise	197
	References	199
5	Well Control and Monitoring Program	205
5.1	Introduction	205
5.2	Well Control System	206
5.2.1	Well Control Principles	207
5.3	Warning Signals of Kicks	211
5.3.1	Primary Indicators	212
5.3.2	Secondary Indicators	213
5.4	Control of Influx and Kill Mud	214
5.4.1	Analysis of Shut-in-Pressure	214
5.4.2	Type of Influx and Gradient Calculation	217
5.4.3	Kill Mud Weight Calculation	217
5.4.4	Kick Analysis	221
5.4.5	Shut-in Surface Pressure	225
5.5	BOP Equipment for Well Control System	227
5.5.1	Kick Detection Equipment	227
5.5.2	Kick Management Equipment	230
5.6	Well Monitoring System	238
5.7	Current Practice in Well Control and Monitoring	240
5.7.1	Managed Pressure Drilling	242
5.7.2	Real Time Data Analysis with Dynamic Neural Network	244
5.8	Future Trend on Well Control and Monitoring System	244
5.8.1	Real Time Vibration Measurement	245
5.9	Summary	247
5.10	Nomenclature	247
5.11	Exercise	248
	References	249

6	Formation Pore and Fracture Pressure Estimation	251
6.1	Introduction	251
6.2	Geological Aspects of Rock Mechanics in Drilling	252
6.2.1	Rock Mechanical Properties	252
6.2.2	Underground Stresses	253
6.2.3	Formation Pressure	254
6.2.4	Overburden Pressures	268
6.2.5	Pore Pressure Estimation	274
6.2.6	Fracture Pressure	294
6.2.7	Methods for Estimating Fracture Pressure	296
6.3	Current Development on Formation Pore and Fracture Pressure	312
6.4	Future Trend on Formation Pore and Fracture Pressure	313
6.5	Summary	314
6.6	Nomenclature	314
6.7	Exercise	317
	References	318
7	Basics of Drill String Design	321
7.1	Introduction	321
7.2	Drill String Components	322
7.2.1	Kelly	322
7.2.2	Drill Pipe	322
7.2.3	Tool Joint	326
7.2.4	Heavy Wall Drill Pipe	327
7.2.5	Bottomhole Assembly	328
7.3	Drilling Bit	334
7.3.1	Types of Drilling Bits	334
7.4	Drill String Design	344
7.4.1	Collapse Load	346
7.4.2	Tension Load	348
7.4.3	Other Design Factors	356
7.5	Bit Design	364
7.5.1	Roller Cone Bits	364
7.5.2	PDC Bits	365
7.6	Drilling Bit Selection	366
7.6.1	Situation-1: When Bit Records are Not Available	367
7.6.2	Situation-2: When Bit Records are Available	368
7.7	Drilling Bit Performance	368
7.7.1	Roller Cone Bits	368
7.7.2	PDC Bit	371

7.8	Drilling Optimization Techniques	371
7.8.1	History of Drilling Optimization	373
7.8.2	Parameters for Drilling Optimization	374
7.8.3	Factors Affecting the Drilling Operations	374
7.8.4	How to Optimize the Drilling Operations	376
7.8.5	Traditional Optimization Process	377
7.9	Factors Affecting Rate of Penetration	379
7.10	Rate of Penetration Modelling	392
7.10.1	Established Models for Rate of Penetration	394
7.10.2	Optimization of the Penetration Rate	412
7.11	Current Development on Drill String and Bottomhole Assembly Design	416
7.12	Future Trend on Drill String and Bottomhole Assembly Design	423
7.13	Summary	424
7.14	Nomenclature	424
7.15	Exercise	427
	References	428
8	Casing Design	433
8.1	Introduction	433
8.2	Importance of Casing String	434
8.3	Types of Casing String	435
8.3.1	Stove Pipe and Riser	435
8.3.2	Conductor Pipe	437
8.3.3	Surface Casing	438
8.3.4	Intermediate Casing	438
8.3.5	Production Casing	440
8.3.6	Liners	440
8.4	Components of Casing String	441
8.5	Classification and Properties of Casing	442
8.5.1	Casing Size	443
8.5.2	Range of Length	443
8.5.3	Casing Grade	444
8.5.4	Casing Weight	445
8.5.5	Casing Connections	445
8.6	Manufacturing of Casing	446
8.6.1	Seamless Process	446
8.6.2	Electric-resistance Welding	446
8.6.3	Electric-flash Welding	447
8.7	Rig-site Operation	447
8.7.1	Handling Procedures	448
8.7.2	Running Procedures	450
8.7.3	Landing Procedures	451

8.8	Casing Design and Selection Criteria	451
8.8.1	Factors Influencing Casing Design	452
8.8.2	Design Criteria	454
8.8.3	Approaches of Casing Design	454
8.9	Current Development in Casing Technology	477
8.9.1	Casing Material Development to Protect the Corrosion	478
8.9.2	Development in Casing Connections	480
8.10	Discussions on Some Case Studies	490
8.11	Future Trend on Casing Design Development	497
8.12	Summary	498
8.13	Nomenclature	498
8.14	Exercises	499
	References	500
9	Cementing	503
9.1	Introduction	503
9.2	Applications of Oil Well Cements	504
9.2.1	Cement Applications	506
9.2.2	Variables Affecting Zonal Isolation	508
9.3	Cement Production	508
9.3.1	Production Process	508
9.3.2	Cement Components	509
9.4	Classifications of Oil Well Cements	510
9.5	Cement Properties	513
9.5.1	Density	514
9.5.2	Fluid Loss	515
9.5.3	Thickening Time	515
9.5.4	Viscosity and Yield Point	517
9.5.5	Permeability	518
9.5.6	Compressive Strength	519
9.5.7	Soundness	520
9.5.8	Fineness	520
9.5.9	Hydration of Cement Slurries	521
9.6	Types of Cementing	522
9.6.1	Primary Cementing	523
9.6.2	Squeeze Cementing	524
9.6.3	Plug Cementing	526
9.6.4	Liner Cementing	527
9.7	Oil Well Cement Additives	528
9.7.1	Accelerators	530
9.7.2	Retarders	530
9.7.3	Fluid Loss Agent	530
9.7.4	Extenders	530

9.7.5	Anti-foaming Agent	530
9.7.6	Free Water Control Additives	530
9.7.7	Lost Circulation Control Agents	531
9.7.8	Weighing Agent	531
9.7.9	Dispersants	531
9.7.10	Strength Retrogression Agents	531
9.8	Cementing Design Process	531
9.8.1	Planning Cement Job	532
9.8.2	Factors Affecting Cement Job Design	532
9.9	Laboratory Tests on Cements Slurry	534
9.9.1	Well Specifications	535
9.9.2	Cement Slurry Design	535
9.9.3	Materials	537
9.9.4	Cement Slurry Preparation	537
9.9.5	Thickening Time Test	539
9.9.6	Density of OWC Slurries	540
9.9.7	Free Water Contents	541
9.9.8	Fluid Loss Test	541
9.9.9	Rheological Properties	541
9.9.10	Compressive Strength of Cement	542
9.9.11	Particles Settling Test	546
9.9.12	Permeability and Porosity Tests	548
9.9.13	Micro Structural Analysis	548
9.10	Mechanics of Cementing	549
9.10.1	Cementing Equipment	550
9.10.2	Cementing Processes	551
9.11	Cement Job Evaluation	555
9.12	Cement Volume Calculation	557
9.12.1	Slurry Requirement	557
9.12.2	Number of Sacks	557
9.12.3	Mixwater Needed	558
9.12.4	Additives Needed	558
9.12.5	Displacement Volume Required	558
9.12.6	Duration of Pumping	558
9.13	Practical Calculations	558
9.14	Recommendations for Successful Cementing	564
9.15	Current Development on Cementing	564
9.16	Future Trend on Cementing	565
9.16.1	Depleted Reservoirs	565
9.16.2	HTHP Reservoirs	566
9.16.3	Corrosive Environment	566
9.16.4	Deep Waters	566

9.17	Summary	566
9.18	Nomenclature	567
9.19	Exercises	568
	References	570
10	Horizontal and Directional Drilling	571
10.1	Introduction	571
10.2	Functions	572
10.3	Basic Terminologies	576
10.4	Types of Directional Drilling	580
10.4.1	Horizontal Drilling	580
10.4.2	Multilateral Drilling	583
10.4.3	Extended Reach Drilling (ERD)	585
10.4.4	Coiled Tubing Drilling (CTD)	587
10.5	Well Planning Trajectory	594
10.5.1	Directional Patterns	594
10.6	Directional Drilling Tools	599
10.6.1	Drill Collars (DC)	599
10.6.2	Heavy Weight Drill Pipe (HWDP)	599
10.6.3	Stabilizer	599
10.6.4	Roller Reamers	602
10.6.5	Key-Seat Wiper	602
10.6.6	Cross-over Sub	603
10.6.7	Drilling Jars	603
10.6.8	Deviating Tools	603
10.7	Well Survey	616
10.7.1	Survey Tools	617
10.7.2	Survey Calculation	625
10.8	Geo-steering	635
10.9	Current Trends in Directional Drilling	636
10.10	Future Trends in Directional Drilling	637
10.11	Summary	639
10.12	Nomenclature	639
10.13	Exercise	640
	References	642
11	Well Drilling Cost Analysis	643
11.1	Introduction	643
11.2	Variables Related to Drilling Costs	644
11.3	Types of Well Drilling Costs	645
11.3.1	Rig Costs	646
11.3.2	Tangible Costs	646
11.3.3	Service Costs	646

11.4	Brake Down of Total Well Drilling Cost	647
11.5	Authorisation for Expenditure	647
11.6	Drilling Cost Estimation	649
11.7	Well Drilling Time Estimation	656
11.7.1	Drilling Time Estimation	660
11.7.2	Trip Time Estimation	662
11.7.3	Number of Bit Estimation	662
11.7.4	Connection Time Estimation	664
11.7.5	Coring Cost Estimation	664
11.8	Time Value of Investment	668
11.8.1	Future Value Estimation	668
11.9	Price Elasticity	669
11.10	Current Trend on Drilling Cost Analysis	670
11.11	Future Trend on Drilling Cost Analysis	672
11.12	Summary	673
11.13	Nomenclature	673
11.14	Exercise	674
	References	677
12	Well Completion	679
12.1	Introduction	679
12.2	History of Well Completion	680
12.3	Requirements for Well Completion	680
12.4	Types of Well Completion	683
12.4.1	Open-hole Completion	684
12.4.2	Uncemented Liner Completions	685
12.4.3	Cased and Cemented Completions	688
12.4.4	Perforated Completion	688
12.4.5	Multi-Zone Completions	693
12.5	Factors Influencing Well Completion Design	695
12.6	Completion Equipment and Materials	697
12.6.1	Casing	697
12.6.2	Cement	698
12.6.3	Perforating and Sand or Gravel Packs	698
12.6.4	Production Equipment	700
12.6.5	Landing Nipple	705
12.6.6	Downhole Gauges	705
12.6.7	Perforated Joint	706
12.6.8	Formation Isolation Valve	706
12.6.9	Centralizer	706
12.6.10	Wireline Entry Guide	706
12.6.11	Tubing Hanger	706
12.6.12	Electrical Submersible Pump	706

12.6.13 Wellhead Equipment and Completion	706
12.6.14 Downhole Safety Valve	707
12.6.15 Subsurface Safety Valves	709
12.6.16 Completion Fluids	710
12.6.17 Casing Perforation	712
12.6.18 Filters and Drains for Solid Transport Control	714
12.6.19 Well Stimulation	715
12.6.20 Tubing String and Accessories	717
12.7 Sand Control	719
12.8 Remedial Cementing	721
12.9 Corrosion and Corrosion Prevention	724
12.10 Current Development on Well Completion	729
12.11 Future Trend on Well Completion	733
12.12 Summary	735
References	735
Index	737

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 contaminants 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.

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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.

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