OILWELL DRILLING ENGINEERING

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ASME PRESS

Library of Congress Cataloging-in-Publication Data

Names: Dareing, Don W., author.
Title: Oilwell drilling engineering / by Don W. Dareing, Professor Emeritus,
Mechanical Engineering, The University of Tennessee.
Description: New York : ASME Press, [2019] | Includes bibliographical references.
Identifiers: LCCN 2018053258 | ISBN 9780791861875
Subjects: LCSH: Oilwell drilling.
Classification: LCC TN871.2 .D3323 2019 | DDC 622/.3381--dc23 LC record available at
https://lccn.loc.gov/2018053258

To: Tron and Hannah

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PREFACE

The early 1960s marked the beginning of major research efforts to improve drilling technology. Also, major efforts were underway to develop technology to explore outer space. The slide rule was still an engineering tool, and there was some use of hand calculators. Illinois's computer (ILLIAC), using vacuum tubes, was one of several automatic computers emerging as an engineering and research tool.

The evolution of drilling and space technologies ironically are similar. Both require engines of thrust, navigation, and the ability to make course changes. The Rocketdyne F-1 engine became, and still is, the most powerful engine ever built, producing thrust up to 2 M lbs. Similarly, drill bits require thrust plus rotational power, navigation, and the ability to drill along a prescribed well path to intersect a reservoir at a specified point. Even though there are similarities, navigating through geo-space offers the challenge of unpredictable forces while space travel navigates through variable gravity fields and environmental drag. Both technologies have matured so that trajectories and targets are achievable with high degrees of accuracy and reliability.

The key to drill bit navigation is the ability to monitor drill bit parameters in real time, while drilling several thousand feet into the earth, allowing well path monitoring and control. This was first accomplished in 1960 by a group of research engineers at Jersey Production Research Company (Tulsa, Oklahoma), who designed and tested the first measurement-while-drilling (MWD) system.

A goal of this book is to present the state of the art of oil well drilling technology, much of which has been developed since the early 1960s. This book explains drilling practices in terms of engineering fundamentals. It is designed for undergraduate students, graduate students and entry level engineering professionals who are interested in learning the language of the industry and the technology of oil well drilling.

An early discussion of optimum drilling practices sets the stage for more detailed coverage of key aspects of drilling. Drill bit types and features are discussed in terms of application, performance, footage cost and wear characteristics. Individual cutter load and heat generation is related to cutter density and type in explaining wear in rigid body drill bits.

Hydraulics of drilling starts with fluid power delivered by mud pumps at the surface. Pump power is partially consumed by parasitic fluid losses leaving the remaining portion for bit cleaning, drilling motors and other equipment located within the bottom-hole assembly. Optimizing available hydraulic power within the BHA is an important part of best drilling practices. It is a necessity for proper application of drilling motors and turbines.

Drillstring dynamics and vibration control are special features of the book. Each mode of vibration (axial, torsion and lateral) is discussed in terms of natural frequencies and sources of excitation. Methods for alleviating severe vibrations, especially, in bottom-hole assemblies are explained. The negative impact of premature failures on footage costs is discussed along with factors that affect reliability of drilling tools and drilling cost.

Casing design, following standard practice is covered as well as well control, including kick detection and methods of kick removal from the well bore.

The mathematics of directional navigation, tools, and methods of well path control, including the use of rotary steerable tools is explained. This discussion is made against a backdrop of historical advances in drill bit directional control, navigation and downhole tools.

Every author approaches this subject differently, relying heavily on personal experiences. I have learned much by working for major oil companies and contractors, in addition to academia. Each provided opportunity to develop professionally and to learn from worldwide operations. Of special notice are: Exxon Production Research Company (Houston), Conoco North Sea (London) and Norton-Christensen (Salt Lake City). I am most fortunate to have the opportunity to develop a career in this wonderful professional environment.

Personal friends, who have enriched my career, are Dr. William C. Maurer and Dr Kirk E. Boatright. Dr. Maurer advanced the science of rock mechanics as relates to chip formation and chip hold-down and developed his theory of perfect cleaning. His testing included rock failure caused by an impact chisel in a high-pressure chamber in Exxon's laboratory, field testing, and raised boring in mine cavities. His fundamental work is now a point of reference for measuring efficiencies of drill bit performance.

Dr. Kirk E. Boatright was one of a team that developed and tested the very first downhole tool for measuring real time drilling parameters directly above drill bits while drilling at several thousand feet. Others on this pioneering team included George H. Paff, Paul M. Ferguson, Jack M. Kellner and D. Joe Meador. This initial effort paved the way for a more advanced tool, which I had the pleasure of using. Bottom hole drilling data was subsequently obtained while drilling in Texas, Oklahoma, Louisiana and Canada. This field data was vital in developing mathematical models of drillstring dynamics as discussed in my book.

I am grateful to ASME for the opportunity to publish this technology.

Don W. Dareing
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University of Tennessee
Life Fellow Member, ASME

UNITS OF MEASURE USED IN OILWELL DRILLING

1 bbl = 42 gal
1 ft^3 = 7.48 gal
1 gal = 231 $in.^3$
1 cm = 0.3937 in.
1 cc = 1 mL
1 gal = 3.785 lit

$\gamma_{water} = 62.4\ lb/ft^3$ (fresh water)

$$\gamma_{water} = 62.4\ lb/ft^3 \left| \frac{1\ ft^3}{7.48\ gal} \right| = 8.342\ ppg$$

$\gamma_{salt} = 1.025 \times 62.4 = 63.96\ lb/ft^3$ (sea water; nominal)

$$\gamma_{salt} = 63.96\ lb/ft^3 \left| \frac{1\ ft^3}{7.48\ gal} \right| = 8.551\ ppg$$

$$\gamma_{steel} = \frac{490\ lb}{ft^3} \left| \frac{1\ ft^3}{7.48\ gal} \right| = 65.5\ ppg$$

1 cp = 1.45×10^{-7} reyns

Units of viscosity in reyns are: $\frac{lb\ sec}{in^2}$

Units of viscosity in poise are: $\frac{dynes\ sec}{cm^2}$

1 lb = 448,200 dynes
1 lb = 4.4482 N

Viscosities of Different Fluids

	cp	reyns
Water	1	$1.45\ 10^{-7}$
Ethylene Glycol	20	$29\ 10^{-7}$
Olive Oil	100	$145\ 10^{-7}$
SAE 30	300	$435\ 10^{-7}$
Honey	1500	$2175\ 10^{-7}$