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Lost Circulation and Wellbore Strengthening

Springer

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Preface

Lost circulation, the loss of partial or whole drilling fluid into the formation, is one of the most common and costly problems in drilling operations. Typical scenarios of lost circulation include drilling through pressure depleted zones, deepwater formations, naturally fractured shales, and carbonate formations. Wellbore strengthening is an effective and economic technique to prevent or mitigate lost circulation problem. This technique artificially increases the maximum pressure a wellbore can withstand by bridging or sealing the natural or drilling induced fractures on the wellbore wall. Although a number of experimental studies and field applications of wellbore strengthening have been reported in the drilling industry, the fundamental mechanisms of lost circulation and wellbore strengthening are still not thoroughly understood, and the industry still lacks sufficient models for lost circulation prediction and wellbore strengthening evaluation. This book makes an effort to fill these knowledge gaps.

This book focuses on the underlying mechanisms of lost circulation and wellbore strengthening. It presents a comprehensive, yet concise, overview of the fundamental studies on lost circulation and wellbore strengthening in the oil and gas industry, as well as a detailed discussion on the limitations of the wellbore strengthening methods currently used in the industry. The book provides several advanced analytical and numerical models for the simulations of lost circulation and wellbore strengthening under realistic conditions. Simulation results are presented to illustrate the capabilities of the models and to investigate the influences of key parameters. In addition, experimental results are also provided for better understanding of the subject.

The book is divided into six chapters. Chapter 1 begins with a brief introduction to the definition, scenarios and consequences of lost circulation, and the concept and different methods of wellbore strengthening. This chapter also provides a critical review of fundamental studies on lost circulation and wellbore strengthening.

Chapter 2 covers some background knowledges of drilling-related geomechanics which are closely related to lost circulation and wellbore strengthening. Concepts such as in situ stress, stress concentration around a wellbore, and drilling mud weight window are introduced. Familiarity with these concepts is essential for understanding the mechanisms of lost circulation and wellbore strengthening.

To understand fracture behavior during lost circulation, Chap. 3 describes a numerical model for lost circulation simulation. The model couples dynamic mud circulation in the wellbore and fracture propagation into the formation. It provides estimates of time-dependent wellbore pressure, fluid loss rate, and fracture profile during drilling. Numerical examples are presented to illustrate the effects of several key parameters on lost circulation.

Chapter 4 illustrates the mechanisms of wellbore strengthening in detail. An analytical model based on linear elastic fracture mechanics is introduced which provides a fast procedure to predict wellbore strengthening after bridging the fractures. Moreover, a numerical model is developed which gives a more detailed description of the distribution of local stress and fracture width with wellbore strengthening operations. A couple of experimental studies of wellbore strengthening are also described in this chapter.

Chapter 5 summarizes the properties and features of various lost circulation materials (LCMs) currently used in the drilling industry. Formations with different lithology usually require different LCMs. LCMs suitable for permeable sandstones, low-permeability shales, and carbonate formations are discussed in this chapter.

Chapter 6 provides some recommendations for future endeavors.

The book will help the readers understand quickly the concepts related to lost circulation and wellbore strengthening. It offers valuable information and guidelines for drilling engineers who face lost circulation problem in their wells and want to use wellbore strengthening technique to solve the problem. The book is also useful for industrial researchers and graduate students who perform fundamental researches in this area.

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Contents

Prologue

Lost circulation problems have plagued the drilling industry for many years, with substantial nonproductive time and costs for prevention and remedial actions. While wellbore strengthening is often used to prevent or mitigate lost circulation, there are numerous physical concepts for the different types of scenarios encountered and operational consequences in different types of wellbore strengthening treatments. Thus, the authors, Yongcun Feng and K. E. Gray, provide an overview of fundamental studies on lost circulation and wellbore strengthening and do an admirable job of presenting various analytical and numerical models in a scientific and unbiased fashion.

Although lost circulation is extremely important to the drilling industry, widespread disagreement about both its root causes and the best mitigation strategies still remain. Perhaps this is to be expected, since at a minimum, fully understanding lost circulation requires an in-depth knowledge of pore pressure, in situ stresses, near wellbore stresses, and multiple properties of the formation rock. In addition, procedures for avoiding or mitigating lost circulation require detailed knowledge about drilling fluids and their physical and chemical interactions with all formations within a well or wellbore.

In the early 1990s, improved estimates for pore pressure, fracture gradient, and deviated wellbore stability for wells drilled in the North Sea were needed. At that time, two target reservoir sands were moderately depleted from their original pore pressures of 10.5 ppg and 14.0 ppg, respectively. Fortunately, significant closure stress and fracture gradient data, obtained from injectivity tests and hydraulic fracture stimulation operations, were available. As drilling operations and production related depletion continued over the subsequent 2–1/2 decades, multiple observations were made regarding changes in fracture gradient and lost circulation with respect to depletion.

Leak-off tests in moderately inclined wellbores were only slightly reduced following significant reservoir depletion. Reservoir pressures in both formations were now below 5.0 ppg. It was determined that fracture closure pressure (FCP) and minimum fracture propagation pressure (FPP) had been reduced significantly, as predicted. One dramatic example occurred while cementing a production liner. As designed, the pre-flush successfully removed the filter cake across a depleted sand, and total lost circulation was observed. A subsequent trip inside the casing to determine the fluid level confirmed that the hydrostatic pressure in the wellbore had stabilized at the estimated FPP in the depleted sand. It was also noted that the well had been drilled with an equivalent circulating density (ECD) significantly greater than this pressure, without significant fluid loss.

From these and multiple additional observations, it was determined that the tangential (hoop) stress equation (Kirsch solution) did a reasonably good job of estimating fracture initiation pressure (leak-off), including changes with respect to wellbore orientation and reservoir depletion, as long as the filter cake remained intact. However, with the filter cake removed, or absent, total losses occurred at FPP. Conversely, it was determined that for multiple shallower formations, which consisted mostly of silty shale and carbonates, leak-off tests were lower than expected, with seemingly no benefit from near wellbore hoop stress. It was surmised that the near wellbore stress field was bypassed by preexisting fractures, or there was a lack of filter cake development. It was also observed that there were often significant differences between FCP, FPP, and leak-off pressure, contrary to assertions in the literature.

It was suggested that the depleted formations were being strengthened, with fractures initiated at the wellbore wall and then quickly filled with background LCM, creating a plug at the fracture opening. But observed leak-off pressures were equal to (and not greater than) the hoop stress estimated by the Kirsch solution with no "strengthening." This discrepancy may be explained by an LCM enhanced filter cake forcing fractures to initiate at the wellbore wall, taking advantage of the already present hoop stress. There remains widespread disagreement about this, but interestingly, the LCM recommendations are identical in either case!

In the late 1990s and early 2000s, with a major exploration push into the deepwater Gulf of Mexico (GOM), operators immediately experienced difficulties associated with narrow drilling margins. The pore pressure/fracture gradient window had to be pushed to its limit in nearly every hole section, to ensure there would be an adequate number of casing and liner strings to reach the objective formations. Wellbore breathing (often called ballooning) and lost circulation were often observed at pressures significantly below the previous casing shoe test. Synthetic based mud (SBM) was very popular due to its shale inhibition, increased lubricity, reduced ECD, ease of running and maintaining, and significantly reduced propensity for differential sticking. However, it also had its drawbacks, including higher costs, cuttings disposal issues, potential masking of small gas influxes, and often lower observed fracture gradient compared to water-based mud (WBM). The widespread availability of logging while drilling (LWD) tools now made it possible to observe where wellbore breathing and lost circulation events were occurring. Interestingly, these losses were often seen in silty or ratty shale, often but not necessarily, at the transition between clean shale and sand. Furthermore, wellbore breathing was almost exclusively associated with nonaqueous drilling fluids. Several operators reported incidences of switching back to (WBM) in a particular hole section, in order to continue drilling with fewer mud losses and avoid setting casing prematurely. Significant work was being performed to describe the differences in FPP pressure between WBM and SBM, which focused on the major filter cake property differences within a fracture. The WBM filter cake was apparently superior for isolating the fracture tip from the wellbore pressure, thereby increasing FPP.

In addition, the numerous "lost circulation pills" formulated by various service companies for squeezing into and sealing fractures, required dewatering once in place in order for the fracture to close and seal around them. It was observed that these pills rarely performed well, unless they were mixed in a water-based carrier fluid. Otherwise, they would not effectively dewater into the shale and allow the fracture to close. This observation led to consideration of wettability of the silty shale formations (usually water wet) and associated capillary entry pressures for non-wetting phase SBM, as playing a significant role in lost circulation pill dewatering. It was also considered that this same phenomenon may be partially responsible for the improved filter cake properties for WBM compared to SBM, inside a fracture.

Despite improved understanding of wellbore breathing and lost circulation with SBM, results of mitigation strategies remain mixed. Pills that do not require dewatering are available, but operations to spot them are still expensive and time consuming, and these pills are frequently eroded by subsequent drilling operations. Some operators have focused more on ECD reduction methods for improving drilling margins, including constant bottom hole pressure techniques.

While lost circulation and its control have been studied extensively and significant advances have been achieved, knowledge gaps and unsolved problems still pose significant nonproductive time and costs for the drilling industry. Additional studies are needed, and topical recommendations by the authors of this monograph include: preexisting fractures; thermal effects; time-dependent developments of external and internal mudcake; numerical models to simulate transportation and deposition of LCMs in fractures; bridging/plugging processes; fracture geometry during drilling for selecting/adjusting size distribution of LCMs in real time; improved or new logging while drilling techniques for acquiring better knowledge of drilling-induced or preexisting natural fractures; lost circulation in carbonates; LC events in anisotropic/heterogeneous formations with complex lithology, stress, and pressure profiles; advanced LCMs that are both reservoir and environment friendly.

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