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Modeling Fluid Interfaces During Cementing Using a 3D Mud Displacement Simulator

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Abstract

In completion of oil and gas wells, cementing operations are employed to provide zonal isolation, a means to prevent wellbore fluids from contaminating sensitive zones such as freshwater aquifers. Perhaps the most important factor engineers and operators should consider for successful cementing is adequate drilling-fluid removal, or "mud displacement." To help optimize mud removal, the primary technique used is to pump a spacer fluid with modified rheology that creates a favorable fluid-fluid interface to enhance mud displacement. In many instances, it is highly desirable to monitor how this interface evolves over time. Fluid intermingling may inhibit the ability of a fluid to perform its intended purpose, for example, intermixing of spacer fluid with cement slurry may lead to contamination of the cement. This contamination may cause an undesirable failure of the setting of the cement and, consequently, a significant increase in cost because of increased wait time or remedial repair.

Therefore, a three-dimensional (3-D) simulator modeling the intermixing of wellbore fluids in a highly eccentric annulus with casing reciprocation and rotation has been developed. The computational system is formulated on a general curvilinear coordinate system whose boundaries can conform to irregular boreholes such as those with washouts. Unlike existing models limited to weakly eccentric annuli without casing movement, the present simulator handles multiple real-world effects and efficiently performs trade-off studies that can enable more economical and effective cementing jobs. The finite difference model provides visual output useful in prejob design and post-job analysis. Among these outputs are 3-D color plots illustrating axial velocity, concentration, viscosity, and density evolution.

Introduction

Efficient mud displacement is perhaps the most important factor in providing a successful cement job. The primary technique used today is to pump a spacer fluid ahead of the cement slurry. Several other factors that directly impact mud displacement are also known, including wellbore geometry, mud conditioning, casing movement via reciprocation and rotation, casing centralization, and optimizing the pump rate.[1,2] However, it is often unknown the extent to which these variables affect mud displacement, especially when applied in combination with one another. Even a relatively straightforward cementing operation can quickly become a challenging scenario with multiple variables. The industry has conducted numerous large-scale physical studies[3-8] over the last half-century to empirically evaluate the importance of these factors on displacement efficiency.

More recently, however, a number of studies have taken advantage of computational numerical methods to describe the different aspects of the mud displacement process in annular geometries. Tehrani *et al.*[9] discuss combined theoretical and experimental studies of laminar displacement in inclined eccentric annuli. The authors appropriately couple the momentum equation with the concentration equation suggested earlier by Landau and Lifshitz.[10] Cui and Liu[11] address helical flow in eccentric annuli based on the bipolar coordinate system. Pelipenko and Frigaard[12] examine fluid-fluid displacement in a two-dimensional (2-D) "narrow annuli" without casing reciprocation or rotation. The well known model discussed by Escudier *et al.*[13,14] considers non-Newtonian viscous helical flow in eccentric annuli for a single fluid. Dutra *et al.*[15] analyzes the interface between adjacent fluids through 3-D annular eccentric tubes using a commercial computational fluid dynamics (CFD) package. Finally, Li and Novotny[16] propose a Lattice-Boltzmann approach based on single fluid flow between two parallel plates to describe cement displacement behavior.

While a significant amount of noteworthy work has been done in the past, the current authors attempt to build a *comprehensive* CFD model that accounts for all physical parameters known to affect displacement phenomena, namely pump rate adjustments, fluid-fluid intermixing and diffusion, casing standoff, abnormal wellbore geometries, fluid rheology, deviation, casing reciprocation, and casing rotation. While the CFD code is still under development, the current version is capable of producing a variety of qualitative and quantitative results.