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## Fluid Movement Measurements Through Eccentric Annuli: Unique Results Uncovered

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### Abstract

Historically, a cement job was considered successful if the casing could be centralized and if high flow rates could be maintained. Today, however, there are more situations where one or both of these criteria are difficult to satisfy. Centralization in highly deviated wells is often challenging, and wells with low fracture gradients place a ceiling on pump rate. Better understanding of fluid movement through eccentric annuli over a wide range of casing standoffs and flow rates is essential for proper cement placement. In addition, being able to predict where cement slurry is located around the casing is very important. For instance, with an eccentric annulus there is no guarantee that cement returns at surface/mud line means complete cement coverage around the casing. Annular fluid velocities can be quite different between the wide and narrow portions of an eccentric annulus. There currently exists limited measured data on flow through annular sizes common to primary cementing operations.

Therefore, a full suite of physical testing was performed to find differences in velocities and flow rates on the wide side vs. the narrow side of a true annulus. Nine models were built, each taller than two meters and each with unique annular geometries. The annular sizes chosen are common to primary cementing operations. The flow area was divided at the top of each model to capture wide and narrow side flow variations. The weight of recovered fluid vs. time was recorded and used to determine flow rates and velocities on both sides. In total, over 250 runs were performed in typical annular geometries with pump rates from 1 bbl/min to 7 bbl/min, fluid rheologies from water-thin to highly viscous, and standoffs from 50% to 85%. While most results verified current industry best practices, other results were quite unexpected, for instance, higher annular velocities on the narrow side under certain conditions. A comprehensive analysis of these results and an appraisal of their potential benefits are presented.

### Introduction

In completion of oil and gas wells, cementing operations are employed to ensure zonal isolation. On many production liners, the wellbore geometry is such that very slow flow rates during cementing are required to prevent fracturing/losses. In addition, liner top packers and tie-backs give annular clearances that are quite small. These narrow clearances cause excessive backpressure with normal flow rates, often requiring the use of low flow rate cementing to prevent losses. The other option is pumping cement at a high rate with losses, often with uneconomical and undesired outcome.

This necessity has led some business units to start performing cementing operations at lower flow rates. Years ago, slow flow rate cementing was popular,<sup>1</sup> but the results revealed its limitations and the practice quickly fell out of favor. The most likely causes of slow flow rate cementing failure were poor centralization and poor compatibility between muds, spacers, and cements. Poor centralization caused channeling and poor compatibility caused viscous interfaces leading to channeling. Today, centralizers are better than in the past and higher degrees of centralization are often attempted. The spacers are also better today. Another significant change is cement slurries that are often much thicker than anything pumped years ago. Accurate modeling of this flow phenomena can help uncover the conditions required to achieve a good cement bond around the entire casing string.

Fredrickson and Bird<sup>2</sup> derived an analytical solution for steady-state axial flow of non-Newtonian fluids in a long cylindrical annulus, but their model is limited to concentric (e.g. perfectly centered) inner pipe. Hacıislamoglu and Langlinai<sup>3</sup> extended the analysis to numerically solve the equation of flow in eccentric annulus for yield-power law fluids. In the present study, we will gain a better understanding of non-Newtonian fluid movement through eccentric annuli using a full suite of physical models. There is limited measured data available on fluid movement through eccentric annuli in the pipe and hole sizes common for primary cementing operations. For that reason a testing program was performed. While the data does not try to predict the removal of one fluid by another fluid,<sup>4-10</sup> it does predict how a single fluid will behave in an eccentric annulus.

### Experimental Setup

The goal was to build a set of large-scale apparatus that allowed us to successfully conduct a complete study of steady-state flow response of various fluids in eccentric annuli. Nine pipe-