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EXPERIMENTAL INVESTIGATION OF THE DYNAMICS OF DISPLACEMENT FLOW IN VERTICAL WAVY ANNULI ACROSS VARIED FLOW CONDITIONS

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Abstract— Effective primary cementing is essential for ensuring well integrity, extending the operational life of wells, and minimizing environmental risks from leaks or failures. For over five decades, researchers have studied the displacement of drilling mud by cement slurries in annuli, with a focus on irregular wellbore geometries such as eccentricity, ovality, and rugosity. Among these, eccentricity is the most extensively studied irregularity due to its significant impact on mud removal and displacement efficiency. Studies show that flow rates, viscosity ratios, and density ratios strongly influence displacement stability in both horizontal and vertical eccentric annuli. For example, Malekmohammadi et al. [2] observed stable traveling wave displacements in highly eccentric configurations, while Renteria and Frigaard [3] examined flow instabilities. Zhang et al. [4] demonstrated that higher buoyancy numbers and lower Reynolds numbers stabilize the interface and reduce dispersion in vertical displacements. Research on other irregularities, such as washouts and obstructions, is comparatively limited. Skadsem et al. [5] investigated washout effects and found that residual fluid accumulation depends on eccentricity and inclination. Mitishita et al. [6] studied displacement of non-Newtonian fluids in eccentric annuli with obstructions, showing that eccentricity plays a dominant role. Additional studies revealed that consolidated cuttings beds primarily have localized effects on displacement flows, underscoring the need for further investigation into less-explored irregularities.

Renteria et al. [7] and Sarmadi et al. [8] took a different approach, studying annular displacement flows in geometries derived from real caliper readings. Fourier analysis of borehole diameter variations revealed dominant lower-frequency patterns with superimposed high-frequency roughness. Inspired by this, we designed and constructed a wavy annulus by applying a Gaussian moving-average filter to caliper data from a real wellbore. This smoothed data produced a semi-sinusoidal wavy pattern, which we used to create a wavy annulus and mounted it onto the flow loop we have already had in our lab. Our experiments investigated Newtonian fluid pairs across a range of Reynolds numbers, buoyancy numbers, and viscosity ratios, focusing on how the wavy geometry influences displacement flow dynamics in a vertical orientation. Results demonstrate that the irregular geometry significantly impacts the stability and dynamics of the displacement front, offering valuable insights into challenges encountered during primary cementing in real-world scenarios. By bridging the gap between idealized models and practical conditions, this study provides a deeper understanding of displacement flows in irregular wellbores.

Keywords-component; displacement flow, wavy annulus, Reynolds number, bouyancy number.

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