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Enhanced Wellbore Integrity Through Pumice-Modified Cement Systems: A Novel Approach for Hydrogen Storage Applications

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This research investigates the application of pumice-modified cement systems in improving wellbore integrity for hydrogen storage wells. Laboratory experiments conducted on cement compositions containing 5-25% pumice by weight demonstrated significant improvements in both mechanical properties and gas containment capabilities. The optimal blend (15% pumice) exhibited a 40% reduction in gas migration along the cement-casing interface and a 35% increase in bond strength compared to conventional cement systems. Under simulated downhole conditions (75℃, 150 bar), the modified system showed remarkable resistance to temperature-induced stress cycling, maintaining structural integrity after 100 thermal cycles (25-75℃). Microstructural analysis revealed that pumice addition created a refined pore network that enhanced cement-formation bonding while reducing permeability. Notably, the system demonstrated superior resistance to hydrogen-induced degradation, with only a 2% strength reduction after 6 months of exposure to hydrogen at storage conditions. These findings provide crucial insights for designing more reliable wellbore barrier systems in hydrogen storage applications, particularly in preventing gas leakage and maintaining long-term well integrity.

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