Biological Sulfate Reduction of Reverse Osmosis Brine Concentrate: Batch Reactor and Chemostat Studies

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The University of Southern California, in conjunction with the Desalination Research and Innovation Partnership—a consortium of California utilities and universities—is developing innovative and cost-effective technologies for large-scale desalination of brackish water supplies. Reverse Osmosis (RO) was chosen for its proven reliability and potential for large-scale application. Prior research has shown that RO recovery is constrained by precipitation of sparingly soluble inorganic minerals such as calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), barium sulfate ($BaSO_4$) and strontium sulfate ($SrSO_4$). Inorganic mineral precipitation may be controlled at lower recoveries by using antiscalants or by controlling feed water pH, however, at higher recoveries (>85 percent) antiscalants may not be effective and pH control does not effectively prevent precipitation of sulfate containing minerals onto RO membranes. Thus, water production goals (95 percent or greater) cannot be cost-effectively achieved without, at some point, lowering levels of sparingly soluble mineral component ions (e.g., calcium or sulfate ions, i.e.Ca^{++} or $SO_4^{=}$). While several treatment options exist (i.e., pretreatment or post treatment), post-treatment, after a primary RO process, offers several benefits: (1) flow volumes are substantially reduced, (2) ions are concentrated to saturation or supersaturated levels and, consequently, may be removed at higher efficiencies, and (3) the primary RO process, which would recover most of the water, would not be affected by process changes or upsets in a post-treatment strategy.

This project will evaluate a new technology to recover reverse osmosis (RO) concentrate produced from desalting high-sulfate waters. The process uses biological sulfate reduction (BSR) to lower sulfate concentration, which concomitantly lowers saturation levels of sparingly soluble mineral salts. This research will focus on evaluating biological kinetics and pertinent operating variables in the BSR reactor.

An electron donor (e.g., ethanol, hydrogen, or acetate) is first added to the primary RO concentrate; sulfate is then biochemically reduced to sulfide in a fluidized-bed, biological reactor. The BSR reaction is favorable under anaerobic conditions when an adequate carbon source (electron donor) is present. Effluent from the BSR reactor is subsequently acidified and sparged to strip reduced sulfur (as H_2S) and aqueous CO_2 from solution. Hydrogen sulfide, and other reduced sulfur species in the off gas, must be neutralized (i.e., oxidized back to sulfate) prior to off gas discharge. Finally, biological solids are removed in a filtration step and the process stream is subsequently sent to a secondary RO process where approximately 70 percent of the water is recovered as a low-total dissolved solids (low-TDS) product.

This study provided estimates of sulfate reduction reaction kinetics under various process conditions, and set the stage for the design of the fluidized bed adsorber reactor (FBAR) process for biological sulfate reduction. The best and the most economical carbon sources were identified based on thermodynamic analysis of electron donor and electron acceptor reactions. Ethanol and acetate were identified as the best among various carbon sources for biological sulfate reduction. Batch bioreactor studies were conducted to determine the effects of pH, temperature, and carbon-to-sulfur (C/S) ratio, and compare the performances ethanol and acetate as carbon sources. After the near optimal pH, temperature, and C/S ratios were determined from batch studies, chemostat studies were conducted under carbon-limiting and sulfate-limiting conditions for both ethanol and acetate as carbon sources. These chemostat studies were specifically designed to determine the biological parameters such as the Monod coefficients, microbial yield coefficient, and the microbial decay coefficient for both ethanol and acetate as carbon sources.

Chemostat studies provided good estimates of biomass concentrations, sludge age or solids detention time, hydraulic retention time requirements for the FBAR systems, and also set limits for biomass washout and enzyme inactivity. Chemostat studies also provided other important FBAR design parameters including the specific microbial growth rate, specific sulfate reduction rate, best organic carbon source, reactor organic loading, and ratio of mass carbon source utilized to mass of sulfate removed. The relevance of these aspects in the design and optimization of the FBAR system will be discussed.