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A double free boundary model for biofilm growth and microbially induced corrosion in wastewater concrete pipes

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Microbially induced corrosion (MIC) is a significant global issue impacting infrastructure, economies, and environment. In wastewater systems, MIC is primarily associated with biofilm formation on concrete sewer pipes, leading to severe degradation due to microbial metabolic activity. The proliferation of sewer biofilms occurs in both submerged and unsubmerged conditions, leading to distinct microbial communities. Commonly, these biofilms host microorganisms such as fermentation bacteria, hydrogen-producing acetogens, denitrifying bacteria, sulfate-reducing bacteria, sulfur-oxidizing bacteria, and methanogens. In particular, sulfur-oxidizing bacteria play a crucial role in corrosion, as they oxidize hydrogen sulfide from wastewater effluents, generating sulfuric acid that accelerates concrete deterioration.

A one-dimensional model with double free boundaries has been developed to investigate the proliferation of biofilms and the related corrosion process in wastewater concrete pipes. The domain is composed of two free boundary regions: a biofilm that grows towards the interior cavity of the pipe, sitting on a gypsum layer formed by corrosion, which penetrates the concrete pipe. Diffusion-reaction equations govern the transport and the metabolic production or consumption of dissolved substances, such as hydrogen sulfide, oxygen, and sulfuric acid within the biofilm layer. The biofilm free boundary tracks the growth of the microbial community, regulated by microbial metabolic activity and detachment phenomena. The corrosion process is incorporated into the model through a Stefan-type condition, which drives the advancement of the gypsum free boundary into the concrete pipe, governed by microbial production of sulfuric acid.

Numerical simulations have been carried out to investigate the model behavior, encompassing the development and progression of the biofilm as well as the corrosion advancement, with the aim of elucidating the key factors governing both phenomena.