Autonomous Membrane-Based Water Treatment and Desalination

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Membrane-based water treatment and desalination processes are suitable for deployment at various levels of capacity from small home-based systems to systems suitable for municipal, industrial and even agricultural water supplies. Deployment of such water systems, particularly for distributed applications of small systems and where 24/7 of operator availability is infeasible, requires system design and process operational strategies that autonomously respond (i.e., self-adaptive operation) to: (i) fluctuations in water feed quality, (ii) variability of product water use patterns, and (iii) regulatory requirements (setpoints) concerning product water quality and residual stream generation. Self-adaptive operation requires real-time system performance monitoring that can then be used, along with a suitable decision support system, for: (i) managing process and sensor faults detection and isolation, (ii) data imputation to temporarily overcome limitations imposed by faulty sensors (i.e., to allow for appropriate corrective actions), (iii) operation with adjustable product water recovery driven to minimize the volume of generated residual streams, (iv) mitigation of fouling and scaling, (v) forecasting performance degradation, and (vi) system configuration for energy optimal operation with considerations of system physical and operational constraints. In order to address the above challenges, a multi-pronged research and development program was undertaken that includes, but is not limited to, system design and configuration, generation of data-driven models of different modes of system operation capable of handling unsteady state behavior and water feed quality fluctuations, and local and supervisory control to handle and optimize operational strategies. Elements of autonomous operation of distributed water treatment and desalination systems will be described along with specific examples of the development and implementation of flexible design and self-adaptive operation of integrated source water filtration (MF, UF) and subsequent reverse osmosis (RO) desalination and purification of seawater and brackish water, including the application of first-principles and machine-learning operational models.