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Optimum water network design for multipurpose batch plants with a detailed electrodialysis regeneration model

Bazolana, Nsunda Christie

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Abstract

Stringent environmental regulations and economic expansion in the recent decades has justified the need for sustainable water usage in the process industry. The usage of water in multipurpose batch plants is essential in cleaning operations to ensure the integrity of various tasks processed in multipurpose units by avoiding contamination between consecutive batches. This usually requires a considerable amount of water while generating highly toxic effluents. The minimization of water in batch plants is achieved through direct, indirect and regeneration reuse. These techniques are mainly dependent on the schedule of the plant and a flexible schedule usually guarantees an increase in water saving opportunities. While direct and indirect reuse requires capital investments, regeneration reuse involves additional operational costs through the consumption of intensive amount of energy. It is therefore vital to capture the trade-off between water and energy usage and explore their respective cost implications.

This work presents a Mixed Integer Nonlinear Programming (MINLP) formulation that simultaneously optimizes the production schedule and utility consumption in multipurpose batch plants. The amount of wastewater generated in batch operations is minimized through the exploration of direct, indirect, and regeneration reuse opportunities within the plant. Water regeneration is achieved through partial purification of highly contaminated wastewater using electrodialysis. A design model for electrodialysis is included in the formulation in order to allow for simultaneous optimization of water and energy use in the regenerator. The formulation is first applied to two examples from literature for validation. Freshwater savings of 37.4 % and 41.1% are achieved in each literature example while maintaining the revenue at its maximum value. The efficiency of the designed regenerators with respect to their energy consumption is evaluated by comparing the proposed technique with a case where the minimization of energy is not considered. A reduction in energy consumption by 31.6 % and 9.8% for both examples is respectively observed. A study is then undertaken at Amul plant, one of the biggest dairy in the world, in order to assess the practicality of the formulation. The formulation is applied to the raw milk

receiving department (RMRD) where the highest amount of freshwater is consumed. Freshwater and energy savings of 38 % and 95.2% are achieved under the consideration of a single quality of water streams. An economic analysis of the integrated water network is performed and 20 % reduction in the total operating cost of the RMRD is achieved through the implementation of the proposed water minimization technique.