Combined water and energy integration in industrial processes with restricted connections

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Reducing the environmental impact of industrial processes is highly linked with decreasing consumption of natural resources, energy, and water. In the context of climate change, as discussed during the Conference of Parties in Paris (COP21), the efficient use of energy, water and other resources is one of the solutions to substantially reduce the Greenhouse Gas (GHG) emissions from industry.

Industries consume large quantities of energy and water in their processes which are often considered to be peripheral to the process operation. Energy is used to heat or cool water for process use; additionally, water is frequently used in production support or utility networks as steam or cooling water. This obviates the interconnectivity of water and energy and that they must be treated simultaneously to address energy and resource use in industrial processes. Over the past two decades, several studies have been conducted to propose systematic methods for simultaneous optimization of water and energy utilization [1] using mathematical programming techniques or conceptual ones. They cover aspects of the problem from multiple contaminant water streams to integration of wastewater treatment plants. The available test cases in the literature aim at evaluating the performance of these methodologies on simplified examples for demonstration/proof of concept purposes. Existing literature, however, does not consider an industrial case study. Due to highly constrained optimization problems and complex operational structures of industrial processes, conventional optimization methods are often not directly applicable. One major assumption in literature test cases is that any hot stream can exchange heat with any cold stream. This approach, however, becomes difficult in real industrial applications due to geographical and thermodynamic constraints. The concept of restricted heat matching has been studied extensively in the literature in an attempt to consider these often-neglected facets of industrial processes. The proposed approaches from literature specify either that predefined stream pairs cannot exchange heat [2] or that an intermediate heat transfer unit must be used [3] (e.g., steam network [4]) to reduce the penalty of the restriction in terms of utility cost. This concept has previously not been introduced in combined mass and heat integration studies.

The goal of this paper is to systematically address these challenges by integrating a novel mixed-integer linear programming (MILP) methodology for simultaneous optimization of water and energy utilization [5] with an extended methodology proposed in [3] for energy and mass integration in industrial sites with restrictions. Water is often an industrial energy carrier and therefore can be an intermediate heat transfer unit; however, it is also a feedstock or process stream for many industrial processes such as brewing and pulp and paper. In these industries, several unit operations consume or produce water at different quality and temperature levels; ergo, water from the intermediate heat transfer unit (utility network) can be recycled and/or reused in these processes allowing heat recovery and water savings. Furthermore, the efficiency of the energy conversion systems has to be considered in parallel, which implies addressing not only the heat recovery but also the combined heat and power production or the use of heat pumping. The challenge is to first set the problem definition in terms of what information must be extracted, and second, systematically generate the mathematical superstructure that can address these practical complexities. In addition, water storage options are added to the problem and their temperatures optimized to lower the penalty of having restricted connections. The resulting optimization exhibits an integrated process and utility structure for water and heat utilization considering flowrates of varying quality, restricted matches and non-isothermal mixing. An industrial case study is presented and the results are analyzed to express the benefits of such an approach in a real production plant. The potential implications of this work are broad, extending from single-site process/unit integration to industrial symbiosis.

Keywords: pinch analysis, combined water and energy integration, restricted matches, mathematical programming, industrial symbiosis.

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