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A systematic approach for optimized water allocation through solution of large scale water/wastewater networks problems

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Water is a resource of great relevance for the mankind, and its preservation and reuse will be a key priority for the coming decades. As water will become scarcer, optimization of its purification and use is of key importance. One example of water optimization problem is the water/wastewater network problem. Given a set of water sources with different levels of contamination, a set of water users requiring different levels of purity and a list of available water treatment technologies, the water/wastewater network problem involves allocating the sources to the users, while identifying the optimal water treatment network with respect to a defined objective function (e.g. minimization of clean water consumption, minimization of costs, etc.).

Process Systems Engineering (PSE) has the potential to contribute to water preservation, through the development of methods and tools needed to solve the water/wastewater network problem (Karuppiah et al., 2006; Foo 2008). However, due to problem complexity, most of the water networks proposed in the literature are limited to few contaminants and water treatment options, and often do not employ a rigorous model of the processing unit considered. Thus, the previous studies about the water networks are arguably not able to manage the complexity of a real industrial case with multi-contaminants (COD, N, SS, heavy metals, etc) and requiring a selection amongst a myriad of wastewater and water treatment technologies.

In this work, a systematic framework for the formulation and solution of water networks problems is proposed. The optimization problem is formulated as a Mixed Integer Non Linear Program (MINLP), which is solved to identify the best wastewater treatment process among a large set of predefined alternatives, according to selected optimum criteria (Quaglia et al, 2012). The key novelty of the proposed framework is to employ methods and tools for the analysis of the formulated problem and identification of the best solution strategy, in order to allow the solution of large scale problems, as it is required when dealing with real industrial cases. This is an exact (or full) method, which employs incremental decomposition-based solution strategies and includes all strategies which can be employed to solve any network synthesis problem, without affecting the quality of the results. The alternative, called here the pragmatic method, aims at formulating a simplified problem, which can be solved in order to obtain an approximate solution, which is then checked against the original problem to guarantee its feasibility. The simplification strategy is selected in order to minimize the loss of quality of the solution, with the help of analysis tools such as sensitivity analysis. Solutions obtained by pragmatic methods cannot be guaranteed as global optimum of the original problem, and therefore the use of such methods should be restricted to cases which cannot be treated with exact methods. Nevertheless, they represent a valuable approach to obtain approximate solutions of very large and complex problems, which cannot be solved otherwise.

In order to demonstrate and highlight the features of the tool, a case study dealing with refinery wastewater purification is presented.The case study considers 4 water sources (3 wastewater streams - caustic, sour and oily wastewater - at different level of contamination and a clean water stream) and 4 water sinks (3 process water users – boiler feed water, cooling tower make-up and desalter - requiring different level of purities and a water effluent stream). A list of 23 water treatment technologies is organized into a superstructure of possible network configuration, leading to more than 1.4 million possible process networks. The optimization problem is formulated and solved for different scenarios, both with respect to problem data (e.g. contamination levels, emission limits), and to objective function selection (e.g. minimization of treatment costs, minimization of fresh water use, etc.), and the results are qualitatively validated and discussed.

With respect to the water networks presented in literature, the one developed here accommodates a wider range of contaminants and allows for the use of engineering insights in the modeling of the treatment units. This approach constitutes a useful and flexible tool to provide a guideline for the process design of the treatment of different types of wastewater sources, as well as to design wastewater treatment systems for a new plant or retrofit or expansion of existing plants. The tool also allows for the evaluation of the effect of different scenarios e.g. different optimum criteria, wastewater sources, environmental regulations on water discharge, contaminant loads on purified water to recycle etc.

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