Green Engineering:
Integration of Industrial Water Management into the Engineering Classroom

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Abstract

As environmental regulations increase and get stricter, green engineering novel solutions become more appealing to industry. Green engineering approaches look into obtaining new designs/methods that are environmentally benign and also economically profitable. This paper presents a pollution prevention class module that focus on water/wastewater management. Its primary objective is to provide the engineering students with a series of tools to design optimal industrial water networks.

Introduction

Water is a key element for the normal functioning of the chemical and petrochemical industry. Steam stripping, liquid-liquid extraction and washing operations are among the many processes present in refineries and chemical plants where water is intensively utilized.

Several procedures have been proposed to design economical wastewater treatment. With a few exceptions, these procedures rely on the application of certain rules of thumb. The current installations usually merge several waste streams and use appropriate technologies in series to clean this stream before disposal. These are therefore, *end-of-pipe* non-distributed wastewater cleanup solutions. Several papers discuss these options. Belhateche (1995) offers a complete discussion of these technologies.

Starting in the eighties and increasingly in the nineties, water re-use started to become popular as means of reducing the total amount of water intake. This, in turn, not only saves upstream treatment of raw water but also reduces wastewater treatment costs. In addition, the concept of distributing the treatment among the various polluted streams and even decentralizing it is gaining acceptance. Industry and the EPA in the US are also seriously considering and discussing the advantages and disadvantages of zero-liquid discharge solutions as the ultimate goal of green water utilization in process plants.

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Until a few years ago, the problem of water treatment was considered as a set of sequential treatment operations of a single wastewater stream consisting of the wastewater from all unit operations (desalters, strippers, etc). At the same time, without the concept of wastewater re-use, these processes are fed by freshwater only. Such a system is depicted for three water user processes (P_i) and three treatment units (T_i) in Figure 1a. One way of obtaining improved designs is the reuse of wastewater from one process to feed another without sending it to treatment first. This reduces the cost because the overall water intake is smaller (figure 1b). The next step is to introduce a series/parallel designs of the wastewater treatment unit without merging all the wastewater streams (figure 1c). Finally, treatment can be decentralized in such a way that some pollutants are removed from wastewater of selected processes allowing the reuse of these waters (figure 1d).

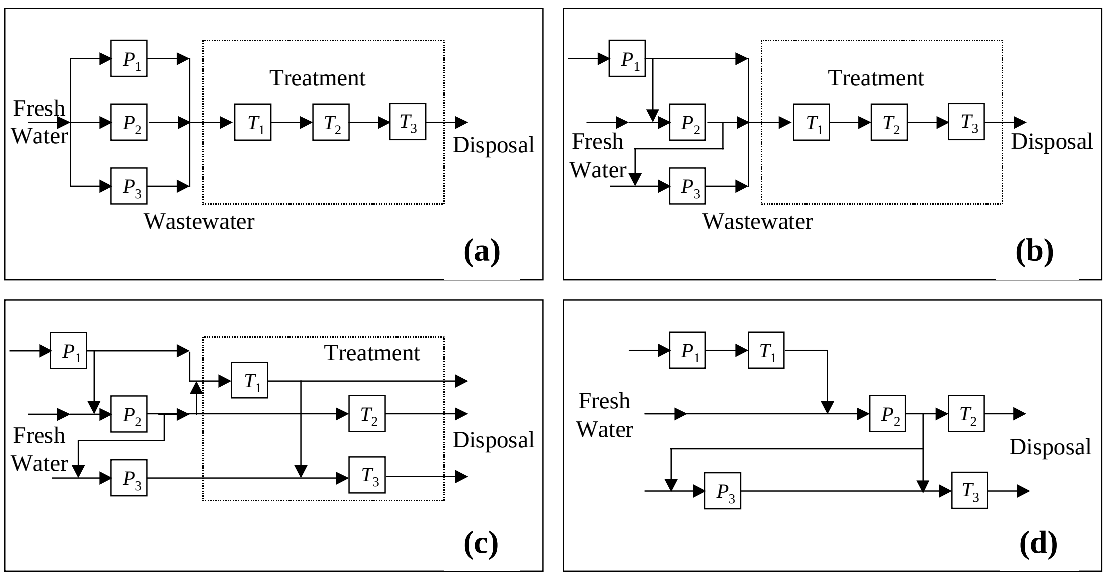

Figure 1. Water Utilization Systems in Process Plants

To attack the problem of at its roots, i.e. the generation of pollutants, process simulation was proposed as a tool to perform pollution balances on processes and calculates pollution indices (Sowa, 1994; Hilaly and Sikdar, 1996). One of the main results of this line of work is the WAR algorithm developed by the United States EPA Risk Reduction Engineering Laboratory. However, for many processes the reduction of the generation of pollutants is not possible. The petroleum processing industry is such an example. The major pollutants in refinery wastewater are part of the crude and are not generated in the plant. Many other pollutants are by-products that are difficult to reduce.
There have been traditionally two approaches used to obtain good designs of these systems:

- Conceptual Approach
- Mathematical Programming.

Because of its graphical nature, conceptual design provides the student with insightful knowledge on how the design can evolve while the mathematical programming approach supplies the necessary tools for implementing new solutions. Recent work is proving that a synergistic combination of both approaches, that is, the use of conceptual insights to help formulating better tractable models for mathematical programming (good initial points, heuristics to help in branch an bound procedures, use of necessary conditions of optimality, etc) is at this point in time showing to be the most effective alternative.

Discussion

The students may come from departments of chemical and civil and environmental engineering.

In the first part of the course, a thorough review on how water is utilized by industry is performed. Different type of industrial applications, the processes involved, and their contaminants are characterized. As motivation, several real industrial case studies are reviewed. This allows students to quantify the importance of water management and its effects in industrial costs as well as the positive environmental impact.

In the second part, graphical approaches such as the Water Pinch (Wang and Smith, 1994) and other grid methods (Gomez *et al*., 1999) are presented. These methods provide the students a very insightful technique on how fresh water can be minimized and wastewater reused. The graphical nature of these procedures makes them easy to understand and apply. Therefore, students can readily tackle single-component water allocation problems and propose water networks featuring minimum fresh water consumption. This part of the course allows the instructor to introduce additional pollution prevention technology such as the concept of *mass exchanger networks* (El-Halwagi and Manousiouthakis, 1989). Algorithmic design procedures, based on optimality conditions (Savelski and Bagajewicz, 1999 a, b), are also covered as a means of systematically solving the single-contaminant case without limitations in problem size.

The mathematical programming methods required that the students first be introduced into concept of engineering optimization. This part of the course is computer intensive. Linear and non-linear programming modeling and superstructure concepts are introduced. Problems are solved using different optimization packages such as those provided in process simulators (ASPEN, Pro II w/Provision), EXCEL, and other widespread solvers such as GAMS/LINDO, GAMS/ CIPLEX, GAMS/CONOPT, and GAMS/DICOPT.

The students obtain then a broad vision of the current available technology and the inherent difficulties and limitations of the methods.

Finally, the optimal wastewater allocation-planning problem is introduced. In this problem, the students face several different polluted water streams that required cleanup before disposal. Also available are different cleanup/ removal processes and an optimal interconnection arrangement is sought.

Summary

This paper proposed the incorporation of new pollution prevention design tools into the engineering curriculum. Several different topics regarding fresh water usage its minimization and reused are covered. Conceptual design and graphical methods are presented as well as rigorous mathematical programming approaches. The course/module provides the appropriate environment to cover other relevant green engineering design techniques and gives the student an overview of mathematical tools and engineering optimization concepts.

The choice of the homework problems, case studies, and the mathematical tools to be used allows the course to be offered as a graduate level class as well.

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