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A Heat Exchanger Networks Synthesis Approach Based on Inherent Safety

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Abstract: An approach to incorporate inherent safety in the synthesis of heat exchanger networks (HEN) based on optimal layouts is given in this work. Hot and cold streams are produced in a set of facilities and some of these facilities may release toxic gas. The geographical allocation where each produced hot and cold stream is then incorporated in the conventional HEN synthesis problem. The number of heat exchangers, area requirement, energy consumption and energy configuration are thus optimally determined. Given are flows, inlet and outlet temperatures for each cold and hot stream as well as sufficient information on cooling and heating services. The annual cost is minimized while allowing for specification of constraints on matches, heat loads and streams splitting. The underlined idea is that inherent safety is achieved when simultaneously producing HEN and optimal facility layouts where risk due to toxic releases is also minimized. The numerical evidence indicates that inclusion of safety layouts with allocations of hot/cold streams can modify conventional HEN synthesis. The resulting model is a highly nonlinear mixed integer program (MINLP).

Keywords: HEN synthesis, inherent safety, facility layout, MINLP.

1. INTRODUCTION

In the chemical and process industry, large amounts of energy and operating costs can be saved through properly optimized heat exchanger networks (HEN). The design and synthesis of HEN has been largely explored and a broad research has been published in the chemical engineering literature. An early method for synthesis of minimum area networks proposed by Hohmann [1] called the attention of several researchers. His work included a strategy to assess feasibility of streams assuming suitable approach temperature and given utility supplies. This technology eventually evolved into what became known as the pinch design method [2]. From a mathematical programming point of view, Grossmann and Sargent [3] gave the first step into the MINLP developments by using an algorithm for discrete variables to solve the HEN problem with incorporated integer variables in the mathematical model. This algorithm was an extension of the method by Ponton & Donaldson [4]. An interesting work has increased stages in previous superstructures by calculating the number of stages based on the inlet temperatures of the hot and cold streams as well as on the exchanger minimum approach temperature [5].

The operation of heat exchangers have been also included in the optimization model to provide flexibility and resilience in HEN designs [6]. Optimal operation of HEN has complemented the typical synthesis problem since the conditions in real plants might be different to those assumed in the design [7-11]. Some of the difficulties to solve during operations due to bad designs have been explored recently [12]. Both online and offline optimization approaches have been implemented to solve optimal process operations [8]. Another operational problem refers to the cleaning of heat exchangers during plant maintenance shutdown. A mixed-integer linear model to detect the optimal set of units to be cleaned during this stage has been recently developed [13].

In general, the main purpose of HEN synthesis became the finding of optimal solutions in an efficient way, and several models were proposed to solve different conditions or scenarios. The proposed approaches have ended up in large mixed integer optimization problems. However, safety has been aside the main goals. More recently, environmental issues based on the eco-indicator 99 have been incorporated [14].

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Original article:

COMPARISON OF FIVE PRETREATMENTS FOR THE PRODUCTION OF FERMENTABLE SUGARS OBTAINED FROM *PINUS PSEUDOSTROBUS* L. WOOD

Juan Carlos Farías-Sánchez[1], Javier López-Miranda[2], Agustín Jaime Castro-Montoya[3], Jaime Saucedo-Luna[3], Artemio Carrillo-Parra[4], Pablo López-Albarrán[1], María Guadalupe Pineda-Pimentel[1], José Guadalupe Rutiaga-Quiñones[1,*]

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ABSTRACT

To benefit from the use of a waste product such as pine sawdust from a sawmill in Michoacán, Mexico, five different pretreatments for the production of reducing sugars by enzymatic hydrolysis were evaluated (sodium hydroxide, sulfuric acid, steam explosion, organosolv and combined method nitric acid / sodium hydroxide). The main finding of the study was that the pretreatment with 6 % HNO_3 and 1 % NaOH led to better yields than those obtained with sodium hydroxide, dilute sulfuric acid, steam explosion, and organosolv pretreatments. Also, HNO_3 yields were maximized by the factorial method. With those results the maxima concentration of reducing sugar found was 97.83 ± 1.59, obtained after pretreatment with 7.5 % HNO_3 at 120 °C for 30 minutes; followed by 1 % of NaOH at 90 °C for 30 minutes at pH 4.5 for 168 hours with a load enzyme of 25 FPU/g of total carbohydrates. Comparing the results obtained by the authors with those reported in the literature, the combined method was found to be suitable for use in the exploitation of sawdust.

Keywords: Reducing sugars, enzymatic hydrolysis, acid hydrolysis, pretreatments, pine sawdust, *Pinus pseudostrobus*

INTRODUCTION

Ethanol can be produced by fermentation of sugars presents in vegetables products (cereals, beet, cane, sorghum, and other biomasses); these sugars are present in the forms of saccharose, starch, hemicelluloses, and cellulose. The product of this fermentation process is hydrated alcohol containing approximately 5 % of moisture. After a dehydration step, the alcohol can serve as a vehicle fuel (SEMARNAP, 2000).

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Synthesis of Eco-Industrial Parks Interacting with a Surrounding Watershed

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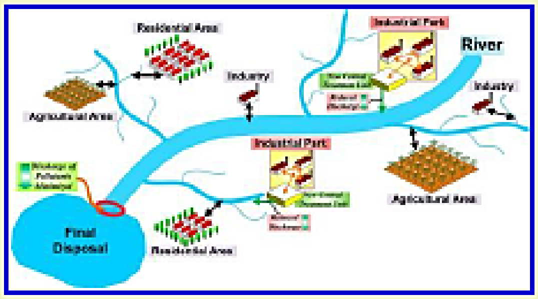

ABSTRACT: Industrial facilities impacting a watershed may be clustered into groups based on their geographical locations. Water usage and discharge for each clustered group of industries may be integrated through the introduction of an eco-industrial park (EIP). This paper presents a mathematical programming model for water integration of EIPs to be synthesized with the purpose of mitigating the environmental impact of industrial effluents discharged into watersheds. The model considers the creation of multiple EIPs, their location, sizing, and tasks. To determine the effect of the discharges on the surrounding watershed, a material flow analysis (MFA) model was coupled with water recycle strategies within the industrial facilities and the associated EIPs. The MFA characterizes the interaction of individual discharges and tracks the impact of the natural (physical, chemical, and biological) phenomena within the watershed on the fate and transport of pollutants. A multiobjective optimization formulation is developed to guide the decisions for multiplant water integration while accounting for the impact on the watershed. The objective function reconciles the minimization of the environmental impact on the watershed, the minimization of the total annualized cost of the water-management system, which includes the cost of fresh water, effluent treatment, and piping and pumping associated with the eco-industrial parks. An example is presented to show the scope and capabilities of the proposed optimization approach.

KEYWORDS: *Eco-industrial parks, Material flow analysis, Water integration, Recycle and reuse networks, Sustainable watersheds*

■ INTRODUCTION

Substantial amounts of water are used in and discharged from industrial facilities. The discharged effluents are typically laden with various pollutants and may lead to major impact on the surrounding watersheds. An effective strategy in reducing water usage and discharge for industrial facilities is to synthesize recycle and reuse water networks for mass integration within the industrial facilities.[1−3] The synthesis of water networks has been extended from intraplant integration to interplant integration through the use of the concept of eco-industrial parks (EIP). In general, the EIP involves industrial symbiosis to integrate various forms of materials and energy as part of the emerging field of industrial ecology.[4−7] In the case of water integration within an EIP, adjacent industries can exchange their resources (in this case water streams) and common infrastructure (e.g., treatment units) to reduce the consumption of fresh resources and the discharge of effluents to the environment.[8−11] Figure 1 shows schematically an EIP composed of several industrial plants where it is possible to recycle wastewater streams to the same plant or to other plants. Additionally, a central treatment facility may be used to receive and treat wastewater streams to enable recycle to the participating plants. Consequently, water integration is improved in the interplant integration compared to the single-plant integration. This integration reduces the overall

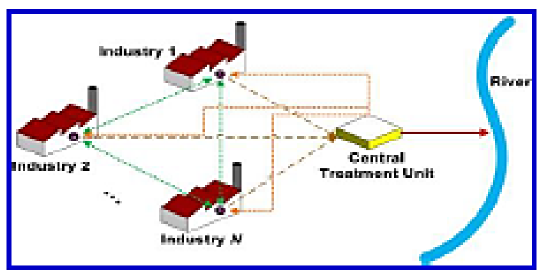

Figure 1. General configuration for an eco-industrial park.

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Article

Simulation of Syngas Production from Lignin Using Guaiacol as a Model Compound

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Abstract: Lignin is an abundant component in biomass that can be used a feedstock for producing several value-added products, including biofuels. However, lignin is a complex molecule (involving in its structure three types of phenylpropane units: coumaryl, coniferyl and sinapyl), which is difficult to implement in any process simulation task. The lignin from softwood is formed mainly by coniferyl units; therefore, in this work the use of the guaiacol molecule to model softwood lignin in the simulation of the syngas process (H_2 + CO) is proposed. A Gibbs reactor in ASPEN PLUS® was feed with ratios of water and guaiacol from 0.5 to 20. The pressure was varied from 0.05 to 1.01 MPa and the temperature in the range of 200–3200 °C. H_2, CO, CO_2, CH_4, O_2 and C as graphite were considered in the output stream. The pressure, temperature and ratio water/guaiacol conditions for syngas production for different H_2/CO ratio are discussed. The obtained results allow to determine the operating conditions to improve the syngas production and show that C as graphite and water decomposition can be avoided.

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Optimal design and integration of solar thermal collection, storage, and dispatch with process cogeneration systems

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HIGHLIGHTS

- A hierarchical approach addresses design of cogeneration systems.
- Separates steady-state optimization from diurnal variability.
- A multiperiod approach optimizes energy mix.
- Integrates expected operation into design.
- A case study involves actual solar data in Saudi Arabia.

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ABSTRACT

This paper introduces an optimization approach to the design of process combined heat and power systems that integrate the thermal profile of the process, an external fossil fuel, and solar energy. A hierarchical design approach is proposed to stage the implementation of steady-state and dynamic calculations. Initially, energy integration is used to identify minimum heating and cooling utility targets. Next, a genetic algorithm approach is employed to optimize the external heating load and generated power of the cogeneration system that includes a steam Rankine cycle. An outer loop is used to optimize the flowrate, temperature, and pressure of the steam entering and exiting the turbine. A multiperiod optimization approach is developed to account for the diurnal variability of solar energy. Direct usage of collected solar energy is considered along with the option of thermal storage and dispatch. The solution of this mixed integer nonlinear program determines the optimal mix of energy throughout the year. A case study for a petrochemical plant in Jeddah, Saudi Arabia was solved to illustrate the applicability of the devised approach.

1. Introduction

Industrial processes are among the largest energy-demanding sectors. Appropriate management of energy within an industrial facility is a challenging task. There are different sources and demands for energy that should be properly matched. There are also different forms of energy (especially heat and power) that are transformed, exchanged, and used in the process. Energy integration techniques have been developed for the optimal design and management of energy throughout a whole industrial process and among different industrial processes. Specifically, energy integration techniques have been developed for the systematic design and optimization of heat exchange networks, process cogeneration that combines heat and power, and process trigeneration which integrates heating, refrigeration, and power. For general reviews of energy integration, the reader is referred to recent the literature on this subject (e.g., El-Halwagi and Foo, 2014; Klemeš, 2013; El-Halwagi, 2012; Kemp, 2009; Smith, 2005). Navid et al. (2014) developed a design approach of cogeneration systems based on economic, exergy, and environmental objectives. Hipólito-Valencia et al. (2014) developed a multiobjective optimization approach to the design of trigeneration systems. Bamufleh et al. (2013) accounted for economic, environmental, and social issues in the design of cogeneration systems. Stijepovic and Linke (2011) proposed a systematic approach to the effective utilization of process heat in industrial zones. An algorithmic approach to the optimal design of cogeneration systems was developed by Al-Azri et al. (2009). The

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ABSTRACT

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Optimal design of integrated CHP systems for housing complexes

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ABSTRACT

This paper presents a multi-objective optimization approach for designing residential cogeneration systems based on a new superstructure that allows satisfying the demands of hot water and electricity at the minimum cost and the minimum environmental impact. The optimization involves the selection of technologies, size of required units and operating modes of equipment. Two residential complexes in different cities of the State of Michoacán in Mexico were considered as case studies. One is located on the west coast and the other one is in the mountainous area. The results show that the implementation of the proposed optimization method yields significant economic and environmental benefits due to the simultaneous reduction in the total annual cost and overall greenhouse gas emissions.

1. Introduction

Cogeneration, also known as combined heat and power (CHP), is the simultaneous production of electric energy or shaft work along with heat from a single energy stream [33]. In cogeneration systems, the efficiency of energy conversion increases to over 80% as compared to an average of 30–35% for conventional fossil fuel fired electricity generation systems (see Fig. 1). This enhancement in energy efficiency can result in lower costs and reduction in greenhouse gas emissions (GHGE) when compared with the conventional methods of generating heat and electricity separately. Successful CHP applications have been reported for industrial systems (e.g., [20,3,15,1]. Cogeneration systems are also suitable for residential and commercial applications like hospitals, hotels or institutional buildings [8]. A cogeneration system is designed with the purpose of satisfying the predicted demands of electricity and sanitary hot water (SHW) of a given consumer [10]. This way, recently there have been reported several approaches for optimizing the use of electric [7,47,12,32,43] and thermal energies [22,9,34] as well as cogeneration systems in housing complexes [35,44,45,46,17,27].

Greenhouse gas emissions as well as other noxious emissions (SO_x/NO_x) can be minimized due to the improved efficiencies, small transmission losses and increased penetration of renewable energy. As an essential supplement of a power system, distributed energy systems can also improve the reliability of the grid, serve as backup or peaking systems and provide energy to remote areas without grid coverage [28]. Although a cogeneration system can be designed to operate autonomously and independently from the electric grid, it is useful to establish a link with the grid to buy and sell electricity [30,26].

An important part of the design problem in cogeneration systems for the residential sector is associated with factors that vary on an hourly or seasonal basis such as energy consumption habits of the home user [14]. Other factors include installation costs, operation and maintenance, CO_2 emissions (GHGE) and environmental conditions [36]. These conditions directly affect the sizing, operating scheme and type of selected prime mover equipment, and they also determine the size of the thermal storage system. These factors have been addressed by optimization models (e.g., [10,16]). Sizing the prime mover system has been undertaken using nonlinear programming problems [11] and linear programming techniques [37] while accounting for economic objectives. Bianchi et al. [5] proposed a technique for selecting and sizing CHP technologies as well as thermal storage systems based on economic objectives and considering environmental and operational parameters. Loken [29] determined the size of storage energy systems in a CHP system using genetic algorithms. Benonysson and Bohm [4] proposed a model to reduce the operating and maintenance costs associated with CHP systems. Jiang-Jiang et al. [25] proposed to use the minimization of CO_2 emissions as a second objective function during designing CHP systems. Furthermore, a common problem in the design of cogeneration systems is the one associated with

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Optimal Design of Energy Supply Systems for Housing Complexes Using Multiple Cogeneration Technologies

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This paper presents a multi-objective optimisation approach for designing residential cogeneration systems based on a new superstructure that allows satisfying the demands of hot water and electricity minimising costs and environmental impact. The optimisation involves the selection of technologies, size of required units and operating regimen of equipment. A residential complex in Mexico was considered as case study. The results show that the implementation of the proposed optimisation method yields significant economic and environmental benefits due to the simultaneous reduction in the total annual cost and overall greenhouse gas emissions.

1. Introduction

Cogeneration (CHP) is the simultaneous production of electrical and thermal energy from a single energy stream (Tahouni at al., 2012). In CHP systems, the efficiency of energy conversion increases to over 80 % as compared to an average of 35 % for conventional generation systems (see Figure 1). It can result in lower costs and the reduction of the greenhouse gas emissions (GHGE) when compared with the conventional methods (Karabegovic, 2014). A CHP system is designed with the purpose of satisfying the demands of electricity and hot water for sanitary use (HWS) (Chicco and Mancarella, 2009). This kind of distributed energy systems can also serve as backup or peaking systems and provide energy to remote areas without grid coverage (Liu et al., 2013). Although a CHP system can be designed to operate independently from the electric grid, it is useful to establish a link with the grid to buy and sell electricity (Lozano et al., 2009).

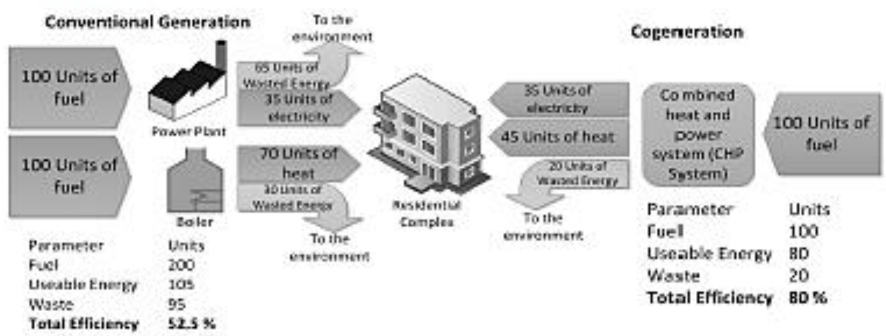

Figure 1: Comparison between traditional generation and CHP systems.

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Optimal Design of Inherently Safer Domestic Combined Heat and Power Systems

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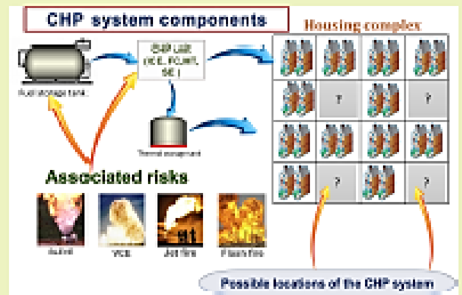
ABSTRACT: The residential co-generation system is a promising strategy to satisfy the electricity and hot water demands in residential complexes. This is an attractive option from both economic and environmental points of view; however, the associated risk has not been accounted for. It is very important to consider the risk associated with residential co-generation systems because the involved units use volatile fuels such as natural gas or liquefied petroleum gas. Therefore, this paper presents an optimization approach for designing residential co-generation systems through a multi-objective optimization formulation that simultaneously accounts for minimizing the total annual cost and the environmental impact as well as the associated risk to satisfy the electricity and hot water demands in a residential complex. The proposed model incorporates the optimal selection for the technologies used as well as the operation. A case study for a residential complex in Mexico is presented to show the applicability of the proposed approach, where it was shown to be possible to obtain attractive solutions from economic, environmental, and safety points of view.



KEYWORDS: *Safety, Domestic combined heat and power systems, Optimal design, Multi-objective optimization*

■ INTRODUCTION

Combined heat and power (CHP) systems are attractive options for energy supply in housing complexes because the simultaneous production of heat and power is more efficient than the single production alone; furthermore, in CHP systems, the costs and greenhouse gas emissions (GHGEs) are reduced compared with conventional generation.[1] However, the design of such systems involves multiple problems; many of them have been solved by optimization algorithms.[2] The most important issues that have been addressed are related to selecting CHP technology,[3] sizing the central co-generation unit,[4] sizing the thermal storage system,[5] determining the interactions with the grid of the local power company,[6] determining the operating scheme for the prime mover,[7] smoothing the gaps between the thermal and electrical demands,[8] and even locating the system.[9] It should be noted that most of the methods used in the studies mentioned above have addressed only economic[10] and environmental[11] targets in the design problems. Also, several different technologies have been proposed to provide access to alternative sources of fuel for CHP units.[12] Furthermore, other works have recently determined the targets for domestic CHP systems[13] and addressed the design problem accounting simultaneously for economic and environmental aspects.[14]

One important point that must be considered in the on-site power generation is related to safety.[15] Therefore, there is a need to account for the inherent safety in the design stage to reduce or eliminate the associated hazard. A process is described as inherently safer if it reduces or eliminates one or more hazards associated with the materials and operations used in the process, when it is compared to some alternative process, and this reduction or elimination is accomplished by characteristics that are permanent and inseparable parts of the process. To appreciate this definition, one must understand the meaning of hazard as an inherent physical or chemical characteristic that has the potential for causing harm to people, property, or the environment. The key to this definition is that the hazard is intrinsic to the material or to its conditions of storage or use. For these reasons, the *inherently safer* approach to risk management is an essential aspect of any safety program. Furthermore, there will be no risk of failure of the layers of protection, and there will be anticipated mechanisms for the occurrence of hazardous events. Inherently safer design is a fundamentally different way of thinking about processes and plants. It focuses on the elimination or reduction of the hazards, rather than on management and control. This approach will ultimately result in safer and more robust processes, and these inherently safer processes will also be more economical.[16] Therefore, the risk factor associated with power generation facilities is one of the dimensions of sustainability.[17] Although several recent papers have considered the environmental aspect in power plants,[18] the inherently safer design is still a pending task in this area.

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Simultaneous design of water reusing and rainwater harvesting systems in a residential complex

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ABSTRACT

This paper introduces an optimization formulation to design residential water systems that satisfy the water demands in a housing complex involving rainwater harvesting, storage and distribution as well as the simultaneous design of water networks for recycling, reusing, regenerating and storing reclaimed water. The design task is considered as a multi-objective optimization problem where one objective is the minimization of the fresh water consumption and the other objective is the minimization of the total annual cost. The proposed model accounts for the variability in the water demands through the different hours of the day and for the different seasons of the year. The seasonal dependence of the rainwater has also been considered in the optimization model. A case study for the city of Morelia in Mexico is presented. The results show that significant reductions can be obtained in the total fresh water consumption and in the total cost.

1. Introduction

With the increasing population, continued urbanization, and overexploitation of water bodies, the world is facing a serious challenge to satisfy the water demands for human activities (CONAGUA, 2014). This challenge has promoted the search of new strategies for the sustainable use of water, including reclaimed greywater reusing and rainwater harvesting. First, in the case of reclaimed greywater reusing, Al-Jayyousi (2003) proposed reusing greywater in arid regions. Mandal et al. (2011) developed a strategy for greywater collection, treatment and reuse to satisfy demands of household sanitary uses and agricultural irrigation leading to freshwater savings up to 48%. Revitt et al. (2011) performed an analysis with empirical data for determining the fate of micropollutants in treatment systems for greywater recycling and obtained savings up to 43% of fresh water. Santos et al. (2012) presented a study for greywater reuse for washing basins and showers. Penn et al. (2013) presented a multi-objective optimization model for the distribution of greywater in an existing municipal sewer system for reuse in toilet flushing and garden irrigation. Chen and Chen (2014) presented an optimization model for recycling effluents from the municipal sewage for industrial use. García-Montoya et al. (2015) proposed a mathematical programming formulation for synthesizing water networks in housing complexes, where reductions of up 38% of fresh water were observed. Zhang et al. (2014) proposed a sustainable design for wastewater reusing in China. On the other hand, for the case of rainwater harvesting, Mwenge et al. (2007) proposed domestic rainwater harvesting to supply water in South Africa. Nolde (2007) implemented an approach for harvesting polluted rainwater obtained from streets and courtyard surfaces. Abdulla and Al-Shareef (2009) reported fresh water savings of up to 19.7% through the use of harvested rainwater. Helmreich and Horn (2009) proposed the use of rainwater treated with slow sand filtration and solar technology for applications in agriculture and households. Sturm et al. (2009) developed a techno-economic analysis for the use of harvested rainwater. Farreny et al. (2011) suggested a type of roof to maximize the availability and quality of harvested rainwater. Gikas and Tsihrintzis (2012) presented an evaluation for the physicochemical properties for harvested rainwater, showing that this is adequate for using in several human activities. Ward et al. (2012) carried out a socio-technical study for rainwater harvesting in UK. Chiu et al. (2009) proposed an optimization model for collecting rainwater through rooftops obtaining savings for the required fresh water and energy. Hashim et al. (2013) carried out a simulation for a large-scale rainwater harvesting system obtaining a significant reduction of fresh

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PROCESS SYSTEMS ENGINEERING

Multiobjective Optimization for Designing and Operating More Sustainable Water Management Systems for a City in Mexico

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This article proposes a multiobjective optimization model for the design of a macroscopic water system of a Mexican city that solves simultaneously the planning and scheduling of water storage and distribution tasks. The model, which considers rainwater harvesting and reclaimed water reusing as alternative water sources, maximizes the revenues from water sales and minimizes simultaneously the water consumption and land use. A case study based on the city of Morelia in Mexico was solved. It was found that the use of alternative water sources (such as harvested rainwater) along with an appropriate planning and scheduling of storage and distribution tasks have the potential to reduce the pressure over natural reservoirs significantly. Our approach considers simultaneously economic and environmental concerns, thereby contributing to the implementation of more sustainable alternatives in urban water distribution. © 2015 American Institute of Chemical Engineers *AIChE J*, 61: 2428–2446, 2015

Keywords: sustainable water use, land use, water consumption, water storage and distribution, scheduling, optimization

Introduction

Recently, research on how to improve water management worldwide has significantly increased due to water scarcity problems arising in several regions of the world. As a result, several approaches for water saving and conservation through water recycling, reusing and regeneration have been reported. An important case is the industrial sector, where several sources of water can be recycled to reduce fresh water consumption (thereby reducing as well the amount of wastewater discharged into the environment). In this context, Gouws et al.[1] presented a review for industrial water minimization involving batch processes. Jeżowski[2] presented another review regarding industrial water networks using graphical and mathematical programming techniques. Besides Verdaguer et al.[3] presented a combinatorial optimization procedure with multiple constraints to treat industrial effluents. More recently, Ibrić et al.[4] implemented a study for industrial water networks for different complexities, ranging from simple water networks up to combined water, wastewater treatment and heat exchanger networks.

Other studies have focused on developing methodologies for the optimal use of water considering the effect of the wastewater discharged from the industries. In this context, Boix et al.[5] proposed a multiobjective optimization strategy formulated as a mixed-integer linear programming (MILP) problem for designing an industrial water network that minimizes the amount of fresh water, regenerated water, and number of network connections in ecoindustrial parks. Alnouri et al.[6] presented an optimization approach for designing interplant water networks involving pipeline design. Furthermore, Burgara-Montero et al.[7] proposed a mathematical programming approach to take into account the effect of the industrial wastewater discharges over the surrounding environment during the synthesis of industrial water networks, and then Burgara-Montero et al.[8] incorporated seasonal variations in this model. Furthermore, Lira-Barragán et al.[9] reported an approach to determine the environmental impact for the industrial wastewater discharges, while Lira-Barragán et al.[10,11] incorporated constraints based on properties and included different options for wastewater treatment. In addition, Martinez-Gomez et al.[12] incorporated safety issues to the industrial wastewater discharges during the synthesis of industrial water networks. Furthermore,

Additional Supporting Information may be found in the online version of this article.

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