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Optimal design of residential cogeneration systems under uncertainty

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ABSTRACT

This paper presents a multi-objective optimization method for designing cogeneration systems in residential complexes and accounting for the involved uncertainty. The model accounts for satisfying the hot water and electric energy demands in a residential complex, while minimizing the total annual cost and the associated greenhouse gas emissions. The proposed model incorporates uncertain data for the ambient temperature, energy demands and prices of the local energy market, which are predicted through forecasting methods for determining the financial and environmental risks. Furthermore, the model accounts for determining the type and size of the central cogeneration unit, thermal storage unit, the needed auxiliary units, as well as the operating conditions. A housing complex in central Mexico is presented as case study. The results show significant economic and environmental benefits for the implementation of the proposed scheme as well as the importance of accounting for the involved uncertainty.

1. Introduction

The economic and environmental benefits yielded through the proper use of resources in the industrial sector have motivated the extension to residential complexes (Cucek et al., 2011; Terrazas-Moreno and Grossmann, 2011; Martin and Grossmann, 2012; Ahmetovic et al., 2014; Ibric et al., 2014; Abdelhady et al., 2015). This way, combined heat and power (CHP) systems have become an efficient alternative for supplying the needed power and heat in residential complexes. This is because CHP systems offer several advantages in terms of efficiency (Maghanki et al., 2013), environmental impact (Peacock and Newborough, 2005) and economic cost (De Paepe et al., 2006; Cravioto et al., 2014) compared with conventional systems. The design of cogeneration systems is determined by several factors, as the availability of natural resources that can feed the system (Tchanche et al., 2014), weather conditions (Lazos et al., 2014), energy demands (Alanne and Saari, 2004), available technologies (González et al., 2015) and the conditions and policies of the local energy market (Streimikiene and Baležentis, 2013). In this context, Collazos et al. (2009) proposed a method for management polygeneration systems. Zhou et al. (2013a) presented an economic assessment for distributing energy in a new residential area in China, and Zhou et al. (2013b) incorporated the impacts of the equipment size in designing cogeneration systems. Fazlollahi et al. (2014) presented a multi-objective optimization approach for designing district energy systems. Recently, Fuentes-Cortés et al. (2015a,b) reported an optimization formulation for designing CHP systems for the residential sector; however, this approach did not account for the involved uncertainty in the system. It should be noticed that there are several uncertain factors involved in the design of CHP systems (Jradi and Riffat, 2014; Li and Ierapetritou, 2008). But, usually designing CHP systems is based on overage values of the parameters that represent significant uncertainty (Gamarra and Guerrero, 2015). Nevertheless, this approach is not the best way to account for the involved uncertainty, since the ambient temperature, the energy market prices and the energy demands are factors that have involved significant uncertainty in designing residential CHP systems (Houwing et al., 2008). These variables have been addressed separately for analyzing CHP systems in the residential sector. In this context, Barbieri et al. (2012) proposed a model to adjust the design of CHP systems to variable energy demands in dwellings. Fubara et al. (2014) studied the seasonal changes in energy demands. Rezvan et al. (2013) used Monte Carlo-based models for determining uncertain energy demands, and Al-Mansour and Kozuh (2007) analyzed the uncertain energy prices in the market. Ren and Gao (2010) presented an analysis for the variations of electricity price through a year. Rysanek and Choudhary (2013) accounted for the installation costs and annual electricity demand. Arnold and Yildiz (2015) incorporated Monte Carlo models for the prediction of energy prices in distributed generation systems. Carvalho et al. (2011) proposed a model to take into account the influence

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Environmental and economic analysis for the optimal reuse of water in a residential complex

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ABSTRACT

This paper presents an optimization formulation for designing residential water networks involving harvested rainwater and reclaimed wastewater. The design problem is posed as a multi-objective optimization formulation that seeks to balance the objectives of total annualized cost, fresh water consumption, and environmental impact. A life cycle assessment approach is undertaken for estimating the environmental impact. The seasonal dependence of the rainwater is considered in the optimization model. The design approach is applied to a case study for the city of Morelia in Mexico. The results show that significant economic, fresh water consumption, and environmental benefits can be obtained as a result of the proposed approach.

1. Introduction

Nowadays, water management is an important issue in the design of residential complexes due to the decrease in fresh-water supplies compared to the residential demand. Additionally, there are negative environmental consequences for the discharge of residential wastewater if not treated properly. For example, in Mexico, the water availability has decreased drastically over a century. In 1910, the fresh water availability was 31,000 m^3 per capita per year. By 1950 it had fallen to 18,000 m^3. In 1970 it was 10,000 m^3 and in 2010 it decreased to 4230 m^3 (INEGI, 2015). Therefore, there is a critical need for strategies that enable proper use of water (Bagatin et al., 2014). In the industrial context, several strategies have been implemented to achieve the optimal use of water resources. Lovelady and El-Halwagi (2009) developed a mass-integration framework for integrating water in an eco-industrial park. Boix et al. (2012) studied water integration in an eco-industrial park considering a single contaminant and a multi-objective function and found that direct integration of the participating companies is the most attractive configuration. Graciano and Roux (2013) presented the use of surrogate models for treatment units in the synthesis of water networks to improve the solution approach. Ibric et al. (2014) implemented an optimization procedure for synthesizing water and energy networks. Lee et al. (2014) addressed the synthesis of multi-contaminant batch water networks, where the objectives were to minimize the water use, wastewater generation, storage capacity and number of interconnections. Chaturvedi and Bandyopadhyay (2014) described the tradeoffs between water use minimization and production in a batch process. Alnouri et al. (2015) developed a water network for an industrial city in which the plant layout was taken into account to select economical pipeline networks that satisfy specific water use requirements. Nápoles-Rivera et al. (2015) presented an optimization approach for planning the water use in a macroscopic system.

The concepts applied in the industrial setting have been extended to the case of single households and residential complexes. In this context, Ghisi and Mengotti (2007) proposed the reuse of reclaimed water and rainwater harvesting in Brazil and found that these systems were not cost effective and that governmental subsidies were required to promote its use in single households. Bocanegra-Martínez et al. (2014) reported an

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Optimal Design of Distributed Algae-Based Biorefineries Using CO_2 Emissions from Multiple Industrial Plants

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Supporting Information

ABSTRACT: This work proposes an optimization approach for capturing carbon dioxide from different industrial facilities to yield an algae-based biorefinery. The proposed approach is based on a distributed system to account for the economies of scale and includes site selection for the processing facilities. Additionally, the model considers optimization for the technologies used in the process stages and different technologies to yield several products. The algae oil that is obtained from each facility can be sent to processing hubs located in the same plant and/or to a central processing unit. The objective function is to minimize the total annual cost for the treatment of flue gases, including the capital and operating costs for the different processing stages and the overall transportation costs associated with the system minus the sales of products plus the tax credit for reducing CO_2 emissions. The results show several economic benefits.

1. INTRODUCTION

The current economy, based on energy production by the combustion of fossil fuels, emits considerable quantities of greenhouse gases (GHGs), especially CO_2. GHGs are considered to be the most important factor contributing to global warming. Since the beginning of the Industrial Revolution, the burning of fossil fuels and extensive deforestation have contributed to an increase of about 40% in the atmospheric concentration of carbon dioxide.[1] In this regard, reducing the CO_2 level in the atmosphere could be a good option for tackling global warming. Therefore, several methodologies have been developed recently for improving energy efficiency[2] and increasing the use of sustainable energy forms[3−7] to overcome the dependence on fossil fuels (such as coal and oil) and reduce CO_2 emissions into the atmosphere.[8] In this context, several works have focused on the mitigation of CO_2 emissions from industrial sectors.[9−13] In addition, one of the most promising strategies for overcoming the dependence on fossil fuels and reducing the amounts of CO_2 discharged into the environment is the use of biomass as renewable energy. For the past decade, microalgae systems have been the technologies with the highest interest for producing biofuels. This is because microalgae production offers some advantages over conventional biomass production, including higher photosynthetic productivity, use of nonproductive land, reuse and recovery of nutrients in the wastewater streams, use of saline or brackish water, and reuse of CO_2 from flue gases from power plants or similar sources.[14] It should be noted that algae systems are particularly promising for the production of biodiesel, but today, they are still too costly.[15] One of the main bottlenecks in algae production is the great amount of energy used in the overall process and the associated investment costs.[16] Therefore, investigations into algae processing must be focused on minimizing the energy usage.[17] Then, it is also desirable to integrate liquid industrial effluents and flue gases into algae systems.[18] Thus, Pokoo-Aikins et al.[19] presented a techno-economic analysis of an integrated system for an algae-based biorefinery using carbon dioxide from the flue gases from a power plant. Rizwan et al.[20] developed a mathematical formulation to determine the optimal pathway for biodiesel production from algae biomass. Martín and Grossmann[21] addressed the optimal use of waste cooking oil and algae for the production of second-generation biodiesel. Murillo-Alvarado et al.[22] presented a methodology for identifying the optimal biorefinery pathway considering technological, environmental, and economic objectives. de la Cruz et al.[23] performed a rigorous simulation including energy integration for the production of substitutes for diesel from algae. Gong and You[24] developed a mixed-integer nonlinear programming (MINLP) model for minimizing unit carbon sequestration and utilization costs based on a novel superstructure that considers the corresponding stages of an algae-based biorefinery. In addition, recent articles have reported MINLP models for optimal algae-based biorefineries that take CO_2 mitigation into account.[25−27] On the other hand, several works have addressed sustainable biorefinery designs (with simultaneous evaluation of the economic and environmental impacts) and planning of supply chains related to biomass conversion, as well as the production of liquid transportation fuels,[28] hydrocarbon biofuels,[29] and multiple products[30] from algae biomass. It is noteworthy that there is no methodology that simultaneously accounts for

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Optimal Safe Layouts with Heat Exchanger Networks Synthesis Having Isothermal Process Streams

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This paper proposes a new MINLP model for heat exchanger network synthesis considering streams with phase change and their geographical allocation based on safety. For heat exchanging, the model includes streams with latent heat, streams with sensible heat, and streams with both latent and sensible heat. Streams may be generated in either an already installed facility or in a new facility for siting, and their point of generation inside the facility is given. For safety, the model considers the possibility of having toxic releases in either installed or for siting facilities. Hence the facilities layout becomes a part of the HEN synthesis optimization problem. A grid layout is adopted to allocate facilities in the available land and a new strategy is developed to solve the non-overlapping facilities constraint. This strategy also reduces the numerical difficulties appearing when Euclidian distances are required when calculating safety affectations.

1. Introduction

The design and synthesis of heat exchanger networks (HEN) has been substantially improved along last decades due to the high economical savings in the chemical and process industry. 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 to obtain HEN with minimum area, proposed by Hohmann (1972) and described in (Gundepsen and Naess, 1988), called the attention of several researchers. This work included a strategy to assess feasibility of streams assuming suitable approach temperature and given utility supplies. The underdeveloped technology eventually evolved into what became known as the pinch design method (Linnhoff and Hindmarsh, 1983). From a mathematical programming point of view, Grossmann and Sargent (1978) 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 in fact a clever extension of the method developed by Ponton and Donaldson (1974). In particular, the concept of superstructure gave a graphical understanding of the HEN problem (Yee and Grossmann, 1990; Yee *et al*., 1990). 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 (Zamora and Grossmann, 1997). An excellent review on HEN has been elaborated by Furman and Sahinidis (2002). Besides numerical improvements to solve the optimization problem, HEN research and their applications have been evolved in several directions. The operation of heat exchangers have been also included in the optimization model to provide flexibility and resilience in HEN designs (Jäschke and Skogestad, 2014). Some of the difficulties to solve during operations due to bad designs have been explored recently (Jensen and Skogestad, 2008). A mixed-integer linear model to detect the optimal set of units to be cleaned during plant maintenance has been recently developed (Assis *et al*., 2013). 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

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Optimal reconfiguration of a sugar cane industry to yield an integrated biorefinery

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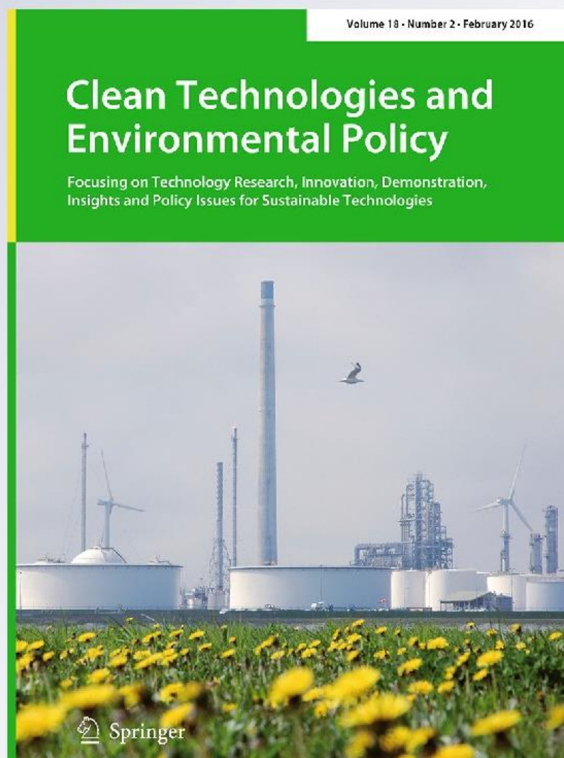

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