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Optimal design of integrated agricultural water networks

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ABSTRACT

This paper presents a mathematical programming model for the optimal design of water networks in the agriculture. The proposed model is based on a new superstructure that includes all configurations in terms of use, reuse and regeneration of water in a field constituted by a number of croplands. The model also includes the allocation of pipelines, pumps and storage tanks in different irrigation periods. The objective function consists in maximizing the annual profit that is formed by the economic incomes owing to the crop sell minus the costs for fresh water, fertilizer, storage tanks, treatment units, piping and pumping. The proposed multi-period optimization problem is formulated as a mixed integer non-linear programming formulation, which was applied to a case study to demonstrate the economic, environmental and social benefits that can be obtained.

1. Introduction

Agriculture is the activity with the highest water demand in the world. Besides it contributes to the water pollution due to the use of nutrients (fertilizers) and pesticides that are discharged as wastewater. Agriculture helps to the ecosystems biodiversity, provides elements to the flue gas capture, contributes to enhance the landscape, is an important factor to combat the world hunger and represents great economic profits (OECD, 2013). In this sense, agriculture is vital to the human being, therefore several technologies and methodologies have been developed to improve seeds, fertilizers, pesticides, process equipment, storage and preservation feeds as well as irrigation systems. The irrigation technologies have been focused on the reduction of fresh water and the application of this resource for increasing the yield of crops. Here, water reduction can be analyzed from two perspectives: (a) *Inside the process*: It consists in finding the best irrigation technique as well as the reuse of wastewater, (b) *Outside the process*: It is related to the reuse of wastewater coming from industrial activities. While a combination of the above scenarios produces a *simultaneous scheme* to consider the reuse of treated water, the irrigation technique as well as the water reuse. Nevertheless, the simultaneous scheme could be a good strategy to optimize the water use in agriculture, the reported works have been focused on reducing the fresh water consumption. In this way, Wilson and von Broembsen (2010) studied the advantages and disadvantages to reuse wastewater in greenhouses. Anderson (2003) presented an analysis about the environmental benefits related to water reusing. Lazarova and Bahri (2004) proposed a strategy for planning water reusing.

Furthermore, the water reusing has been studied from different points of view, including removing heavy metals (Petruzzelli, 1989; Wu et al., 1998), health risks (Chang et al., 1996; Shuval et al., 1997) and irrigation costs (Schleich et al., 1996; Schwarz and Mcconnell, 1993). Hussain et al. (2002) presented a review about the characteristics and international regulations of wastewater utilized in agriculture, and the positive as well as negative impacts owing to the use of treated water. Besides, the rainwater harvesting has been the most used strategy to meet with the water demand for the agriculture in several parts of the world. In this regard, several works dealing with the hydrological impact on watersheds due to the application of domestic and agricultural rainwater harvesting have been reported (Ghimire and Johnston, 2013). Other approaches have implemented economic analysis of different rainwater harvesting structures (Goel and Kumar, 2005). Furthermore, Hatibu et al. (2006) determined the economic aspects of harvesting rainwater, He et al. (2007) analyzed the factors that affect the rainwater harvesting, and Jiang et al. (2013) presented the benefits in the consumption of fresh water and energy associated to the rainwater harvesting. In addition, some reviews about rainwater harvesting have been

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Optimal design of domestic water-heating solar systems

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Sustainable Multi-objective Planning of Biomass Conversion Systems under Uncertainty

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Recently, the biomass has gained considerable attention as a feedstock for energy production because of its attractive characteristics, including its availability as a renewable resource. However, the biomass can be subjected to several uncertain factors such as the availability, market cost and composition; thus, it is worth noting that the uncertainty in the raw material can affect drastically the final supply chain configuration of the product. Therefore, this work presents a new approach for the optimal planning under uncertainty for a biomass conversion system involving simultaneously economic and environmental issues. In this context, the EcoIndicator99 method was used to assess the overall environmental impact in the entire supply chain. Additionally, the economic aspect takes into account all the costs associated to the different activities as well as the costs for raw materials and the sale of products. The proposed method considers the uncertainty involved in the supply chain through the raw material price by the stochastic generation of scenarios using the Latin Hypercube method followed by the implementation of the Monte-Carlo method for determining the optimal structure for each sample. Furthermore, with the proposed approach is possible to select the more robust structure for the supply chain based on statistical data. On the other hand, the proposed approach incorporates an analysis based on the standardized regression of the uncertain coefficients within the supply chain to determine the magnitude in which the uncertain data affect the value of the considered objectives. The proposed approach was applied to a case study for a distributed biorefinery system in Mexico, considering 6 suppliers, 6 processing facilities as well as 5 distribution centres. Besides, 9 raw materials were contemplated to obtain 5 different products through 2 processing routes.

1. Introduction

Biomass appears to be a viable raw material to replace oil for the production of several valued-added products, especially biofuels through biorefineries. However, its implementation requires the exploration of several aspects, including the selection of feedstocks, processing routes, products, harvesting sites, processing and markets, as well as numerous other sustainability criteria. Recently, the optimization of supply chains (SC) associated to biorefineries and the multi-objective optimization of SC based on biomass conversion that include environmental and sustainability implications have gained the attention of the industry and academia. With respect to the consideration of the environmental issue in applications for supply chains, Czarnowska et al. (2014) analysed several methods to measure the environmental impact such as the methods based on life cycle assessment. Also, with respect to the multi-objective optimization, Kravanja and Čuček (2013) presented two multi-objective approaches for synthesizing sustainable systems for biogas production, both approaches considered a single product and the change over time was not taken into account. El-Halwagi et al. (2013) introduced a new approach for the incorporation of safety criteria into the selection, location, and sizing of a biorefinery.
More specifically, for the optimal planning of supply chains, Koltsaklis et al. (2013) presented a mixed integer linear programming model for the optimal planning of a national power generation system. In addition, a mathematical model able to incorporate economic, environmental and social aspects was

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A mixed-integer dynamic optimization approach for the optimal planning of distributed biorefineries

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ABSTRACT

The implementation of supply chains based on biomass conversion requires the exploration of various aspects, including the selection of processing technologies, configuration of the supply chain, portfolio of products as well as the feedstock selection. One important feature of this system is that the composition of the available biomass changes drastically through the year because this depends significantly on the climatic conditions; this way, the dynamic behavior of this process is an important issue that must be considered. This study presents a dynamic optimization model for the optimal planning of a distributed biorefinery system taking into account the time dependence of the involved variables and parameters. In addition, this paper incorporates a model predictive control methodology to obtain the behavior of the storages and orders of the supply chain; where the objective function is the difference between the required and satisfied demands in the markets. Therefore, this study considers relevant issues, which include the multiple available biomass feedstocks at various harvesting sites, the availability and seasonality of biomass resources, potential geographical locations for processing plants that produce multiple products using diverse production technologies, economies of scale for the production technologies, demands and prices of multiple products in each consumer, locations of storage facilities and a number of transportation modes between the supply chain components. The model was applied to a case study for a distributed biorefinery system in Mexico. Results show that is possible to get the configuration and the behavior of the supply chain considering its dynamic behavior in a rigorous way; furthermore, the solutions obtained by the model illustrate that the supply chains based on biomass conversion are seriously affected by the availability of bioresources over the time.

1. Introduction

Currently, the increasing demand of energy around the world and the problems related to the climate change caused by greenhouse gas emissions (GHGE) from burning fossil fuels have promoted the use of alternative energy sources such as biofuels (Clark et al., 2006). Biomass has gained considerable attention as feedstock for energy production because of its attractive characteristics, including its availability as a renewable resource, reduction of GHGE, creation of new infrastructure and the inherent flexibility of biomass to produce several products (biofuels, polymers, specialty chemicals, etc.). These reasons have motivated the research for synthesizing novel processing pathways or technologies associated to biorefineries.

Recently, the optimization of supply chains (SC) associated to biorefineries has gained a lot of attention (Shah, 2005). This way, Hosseini and Shah (2011) and Yue et al. (2014) described the key challenges and opportunities in modeling and optimization of biomass-to-bioenergy supply chains; they demonstrated that multi-scale modeling and optimization play an important role to address these challenges. Hosseini and Shah (2011) concluded that one of the key challenges in the field is to integrate the different components of supply chains without any prior assumption about the fundamental structure of the network.

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AIChE

Optimal Planning for the Reuse of Municipal Solid Waste Considering Economic, Environmental, and Safety Objectives

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A mathematical programming model is presente for the optimal planning of the reuse of municipal solid waste (MSW) to maximize the economic benefit while simultaneously considering sustainability and safety criteria. The proposed methodology considers several phases of the supply chain including waste separation, distribution to processing facilities, processing to obtain useful products, and distribution of products to consumers. Additionally, the safety criteria are based on the potential fatalities associated with waste management. The proposed optimization model is formulated as a multiobjective optimization problem, which considers three different objectives including the maximization of the net annual profit, the maximization of the amount of reused MSW, and the minimization of the social risk associated with the supply chain. The proposed model is applied to a case study in the central-west region of Mexico. The results show the tradeoff between the social risk and the economic and environmental criteria. © 2015 American Institute of Chemical Engineers *AIChE J*, 61: 1881–1899, 2015
Keywords: supply chain, waste management, social risk assessment, optimal planning, multiobjective optimization

Introduction

Nowadays, municipal solid waste (MSW) management is an important practice that addresses critical societal needs. The enormous generation of MSW is directly related to the current human lifestyle. Over the past decade, MSW disposal has increased drastically from 0.5 kg/(person day) to 1.7 kg/(person day).[1] This has represented a serious problem particularly for countries where effective strategies for MSW management are not well established.[2] Inappropriate waste disposal may lead to serious side effects including groundwater pollution, health risks, and serious safety issues such as fire and explosion that may lead to fatalities.[3] As such, a sustainable and efficient waste management strategy is needed to balance the need for the development of the quality of human life and the protection of the environment.[4] For the optimal planning of MSW management, it is necessary to consider the entire supply chain of the system including tasks like MSW recollection, transportation, treatment, production of value added products, and distribution of products.[5] In this context, Varbanov et al.[6] introduced a new indicator, called waste energy potential utilization, to measure the impact of logistics and energy distribution from MSW. Hokkanen and Salminen[7] reported a methodology to take into account several criteria for the selection of a MSW management system. Hung et al.[8] presented a review of models to support the decision making in MSW management. In addition, a classification for the models utilized in the area of MSW management was reported by Morrisey and Brown[9] and Karmperis et al.[10] Santibañez-Aguilar et al.[11] proposed a mathematical programming model for the optimal planning of a supply chain for MSW management considering economic and environmental aspects. Also, Tan et al.[4] reported an optimization model for synthesizing MSW processing networks to produce energy and value-added products achieving economic and environmental issues. Bowling et al.[12] developed an approach to determine optimal locations and sizes of biomass-management facilities. Furthermore, Minoglou and Komilis[13] presented a simplified methodology to optimize an integrated MSW management

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Optimal Synthesis of Refinery Property-Based Water Networks with Electrocoagulation Treatment Systems

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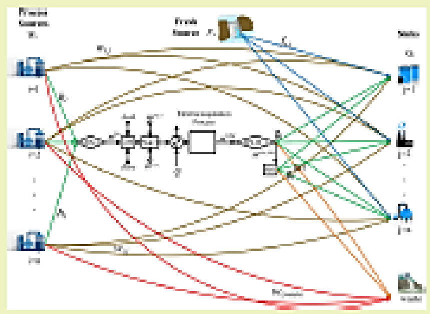
Supporting Information

ABSTRACT: This paper presents an optimization approach to the incorporation of electrocoagulation in the design of integrated water networks for oil refineries. A disjunctive programming formulation is developed to minimize the cost of the water-management system while including the characteristics of process water streams, recycle, reuse, and treatment of wastewater streams, performance of candidate technologies, and composition and property constraints for the process units and the environmental discharges. The performance of electrocoagulation was related to temperature pH and the concentration of phenols and sodium chloride. Ancillary units including pH adjustment, reverse osmosis, and heat exchangers were used to support the electrocoagulation unit. Two case studies are presented to show the applicability of the proposed model and the feasibility of using electrocoagulation as part of an integrated water management scheme for oil refineries.



KEYWORDS: *Electrocoagulation, Recycle and reuse water networks, Optimization, Removal of phenolic compounds, Refinery wastewater*

■ INTRODUCTION

Industrial processes consume tremendous amounts of fresh water and discharge significant quantities of wastewater. Efficient mass-integration strategies that include conservation, treatment, recycle, and reuse are instrumental in reducing water usage and discharge and in abating the environmental impact associated with the discharge of pollutants to water bodies. Three mass-integration approaches have been developed for the design of industrial water networks: graphical (pinch), algebraic, and optimization techniques. For recent reviews, the reader is referred to the works by El-Halwagi and Foo,[1] Klemeš,[2] El-Halwagi,[3] Poplewski,[4] and Foo.[5] Pinch-based methods provide valuable visualization-based understanding of the design of recycle/reuse networks but are limited in terms of scope and size of the problem. On the other hand, mathematical programming techniques can address significantly more complex problems but require specialized knowledge to formulate and solve. A particularly important class of water networks involves the design based on a property integration framework. Property integration is a technique which is based on optimizing the allocation and manipulation of streams to units based on properties. Shelley and El-Halwagi[6] proposed a property-based componentless approach to process integration and introduced the concept of property clusters that can be tracked in a conservative manner. El-Halwagi et al.[7] presented a rigorous graphical targeting approach to minimize the use of fresh resources by using segregation, mixing, and direct recycle/reuse strategies. This approach was revised by Kazantzi and El-Halwagi[8] and Kazantzi et al.[9] to characterize streams and units based on properties through graphical techniques and by Qin et al.[10] and Almutlaq and El-Halwagi[11] through algebraic techniques. El-Halwagi et al.[12] presented new systematic rules and visualization techniques for the identification of optimal mixing of streams and their allocation to units. Furthermore, they presented a derivation of the correspondence between clustering tools and fractional contribution of streams to minimize the usage of fresh resources. Eljack et al.[13] developed property clustering techniques for the simultaneous design of molecular and process networks. Grooms et al.[14] further introduced a source–interception–sink representation to embed structural configurations of interest. Foo et al.[15] introduced two new tools: the property surplus diagram and the property cascade analysis technique to establish rigorous targets on the minimum usage of fresh resources, maximum direct reuse, and minimum waste

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Multiobjective Optimization Approach for Integrating Design and Control in Multicomponent Distillation Sequences

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ABSTRACT: This work introduces a multiobjective optimization approach to integrate the design and control of multicomponent distillation sequences. The evaluation of the control properties and the design of the distillation systems were evaluated through the calculation of the condition number and the total annual cost of each design, respectively. Three distillation systems, including the direct sequence, the indirect sequence, and the dividing wall column along with three mixtures with representative ease of separation index (ESI) values and three different feed compositions, were studied. In addition, in a posterior stage to the optimization process, the Eco-indicator 99 for each design was estimated to quantify the environmental impact of the distillation systems. The results offer the trade-offs between the control properties and the design, which is shown through Pareto optimal solutions that enable selection of the solutions that establish the proper balances between both objectives.

1. INTRODUCTION

Historically, and also common today, the chemical process design and the evaluation of the control properties are two problems approached and solved in a separated and sequential way. In a first stage, the process is designed in order to achieve the aims of the design (e.g., the product specifications that meet the requirements of the markets), and in a second stage the control aspects are analyzed and solved. This sequential methodology may present some deficiencies such as dynamic constraint violations, process overdesign, or underperformance, and a robust performance is not guaranteed.[1] Another disadvantage is related to the way in which the process decisions influence the control operation of the process; in a realistic scenario stated by a competitive market, the chemical processes must operate as flexibly as possible in order to adapt in an adequate way to the changes in the product specifications, the demand of consumers, and the variations in the raw materials. In this context, the utilization of appropriate strategies for integrating design and control would allow the suitable operation of the process by improving the profitability through the increment of the throughput production and also the increment in the yield of high value products, besides the minimization in the energy consumption, pollution, and as a direct consequence the environmental impact. Therefore, the development of the idea of integrating design and control may produce significant economic benefits in addition to improvements in the operation of processes through the incorporation of the assessment of the process dynamics in the initial stages of the design. These interactions between the design and control have been documented in past decades.[2−8] The ideas developed in these works have triggered some of the literature to sketch a general methodology for integrating design and control based on different methods to assess the dynamic properties of the design, for example index-based methods,[9−11] dynamic optimization-based methods,[12−16] robust metrics-based methods,[17−22] and recently probabilistic-based methods.[23] Most of these methodologies approach the integration of design and control; however, only a few have been applied to the simultaneous integration of large scale process such as multicomponent distillation systems.

In general, the integration of design and control becomes an optimization problem that represents a significant computational burden. Therefore, global optimization methods are desirable in order to solve this problem. These methods can be classified as deterministic global optimization methods and stochastic global optimization methods; the first class offers a guarantee of finding the global optimum of the objective function, provided that the objective function is convex. However, strategies in this class often require high computational time (generally more time than stochastic methods) and, in some cases, a problem reformulation is needed. The use of rigorous design and thermodynamic models leads to very large nonconvex models, which are very difficult to converge. Moreover, taking into account structural and design decisions leads to the inclusion of integer variables, further increasing the difficulty of solving the model. Finally, additional convergence problems are generated when discontinuous functions, such as complex cost functions, are introduced in the model. Recently, some deterministic methodologies that integrate design and control have been developed.[24−26] On the other hand, stochastic global optimization methods allow obtaining good solutions in moderate computational time. In addition they are very flexible to implement and easy to use, and additional transformations of the original problem are avoided. This is particularly interesting because medium and large scale optimization problems can be implemented in a reasonable computational time. One of the stochastic methods that has

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