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Decision system based on neural networks to optimize the energy efficiency of a petrochemical plant

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ABSTRACT

The energy efficiency of industrial plants is an important issue in any type of business but particularly in the chemical industry. Not only is it important in order to reduce costs, but also it is necessary even more as a means of reducing the amount of fuel that gets wasted, thereby improving productivity, ensuring better product quality, and generally increasing profits. This article describes a decision system developed for optimizing the energy efficiency of a petrochemical plant. The system has been developed after a data mining process of the parameters registered in the past. The designed system carries out an optimization process of the energy efficiency of the plant based on a combined algorithm that uses the following for obtaining a solution: On the one hand, the energy efficiency of the operation points occurred in the past and, on the other hand, a module of two neural networks to obtain new interpolated operation points. Besides, the work includes a previous discriminant analysis of the variables of the plant in order to select the parameters most important in the plant and to study the behavior of the energy efficiency index. This study also helped ensure an optimal training of the neural networks. The robustness of the system as well as its satisfactory results in the testing process (an average rise in the energy efficiency of around 7%, reaching, in some cases, up to 45%) have encouraged a consulting company (ALIATIS) to implement and to integrate the decision system as a pilot software in an SCADA.

1. Introduction

The applications of expert systems are rapidly increasing in the industry. Such applications are very effective in situations when the domain expert is not available (Shiau, 2011). There are diverse problems which need to be solved in the real world and they are difficult to solve by the expert at the moment of carrying out his work. Thus, the expert systems, and specifically the decision systems, become prolific in many fields (Liao, 2005). On the other hand, data mining (Köksala, Batmazb, & Testikc, 2011), or the step of extracting knowledge from the databases, is a discipline intimately related to expert system and which makes it possible to extract the necessary knowledge to design them.

In chemical industry, one of the complex problems for the control of which a computational intelligent approach is amenable, is a crude oil distillation unit. In a crude distillation process, the first objective is to perform an entire process optimization including high production rate with a required product quality by searching an optimal operating condition of the operating variables. In the previous decade, there was considerable research concerning the optimization of crude distillation process. In Seo, Oh, and Lee (2000), the optimal feed location on both the main column and stabilizer is obtained by solving rigorous "a priori" models and mixed integer nonlinear programming. The sensitivity to small variations in feed composition is studied in Dave, Dabhiya, Satyadev, Ganguly, and Saraf (2003). Julka et al. propose in a two-part paper (Julka, Karimi, & Srinivasan, 2002; Julka, Srinivasan, & Karimi, 2002) a unified framework for modeling, monitoring and management of supply chain from crude selection and purchase to crude refining. In addition to analytical non-linear models, computational intelligence techniques such as neural networks (Liau, Yang, & Tsai, 2004) and genetic algorithms (Motlaghi, Jalali, & Ahmadabadi, 2008) are used for the same purpose. In particular, neural networks have been used for modeling and estimation of processes in petrochemical and refineries (Falla et al., 2006; Shirvani, Zahedi, & Bashiri, 2010; Zahedi, Parvizian & Rahimi, 2010).

The scope of present study is concerned with a part of the crude oil distillation called the platforming unit. It is constituted of two subunits: the catalytic reforming or reaction unit and the distillation unit or train distillation. The decision system is focused on optimizing the production rate of the distillation unit which is the most important zone of the platforming unit since it is the one that concentrates the consumption of the plant.

At present, research is not focused only in the rise of the production rate (Jarullah, Mujtaba, & Wood, 2011; Meidanshahi,

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Bahmanpour, Iranshahi, & Rahimpour, 2011) but also in the improvement of product quality (Iranshahi, Bahmanpour, Paymooni, Rahimpour, & Shariati, 2011; Rahimpour, Vakili, Paymooni, Iranshahi, & Paymooni, 2011). In this sense, classical applications of linear control theories on the distillation unit are widely available in the literature (Jabbar & Alatiqi, 1997). Also nonlinear state estimation research (Jana, Samanta, & Ganguly, 2009) and optimal planning strategy research (Kuo & Chang, 2008) are available. The main objective of these papers was to remove impurities in the distillate (i.e., C_5^+ in the debutanizer column) and maintain the minimum possible amount of product (butane) in the bottom residual fuel oil to maximize the yield of the product.

The aim of our work is to perform a plant energy process optimization, including an adequate production rate with the required product quality but minimizing operating cost (fuel consumption in boilers) through a data mining approach. Several research endeavors have treated consumption analysis as a knowledge discovery problem using intelligence techniques (Li, Bowers, & Schnier, 2010). In De Silva, Yu, Alahakoon, and Holmes (2011), the authors proposed an interesting Incremental Summarization and Pattern Characterization (ISPC) framework for data mining, intelligent analysis and prediction of energy consumption based on electricity meter readings. Both forms of learning, supervised and unsupervised, have been adopted in these studies (Hippert, Pedreira, & Souza, 2001; Metaxiotis, Kagiannas, Askounis, & Psarras, 2003). In Hippert et al. (2001), the unsupervised learning based on the SOM algorithm for the three tasks, namely classification, filtering and identification, of customer load pattern is proposed. Clustering has also been successful in industry applications of data stream mining, such as in Iglesias, Angelov, Ledezma, and Sanchis (2011). The intelligent control algorithms applied to the control of combustion processes have produced satisfactory results and show a great potential for growth. Previous research has shown that boiler efficiency can be optimized with data-mining approaches (Miyayama et al., 1991 and Ogilvie, Swidenbank, & Hogg, 1998). In Kusiak and Song (2006), authors proposed an optimization with clustering-derived centroids. In Song and Kusiak (2007), authors develop a data mining approach for optimizing the combustion efficiency of an electric-utility boiler subject to industrial operating constraints. Latest cited papers offer interesting researches about single boilers. These studies encouraged the authors of the current paper to offer a mining approach to optimize the efficiency of a complete distillation plant, minimizing the operating and economical constraints.

Due to a close monitoring in real-time of the process is, in practice, rarely available, only information collected into an historical database and the data mining software tools were used. The expert's performance is hidden in the collected dataset. This valuable knowledge feeds the proposed decision support system framework. It is not necessary that the global plant control model be reconfigured; the expert's information can simply be extracted. The question that emerges is: Is it possible to extract expert information from the limited amount of data collected in the historical database, searching in past data optimal cost operating conditions? And is it possible to improve energy efficiency by the estimation of new operating condition with a decision system software tool? In this work, we present a decision system, designed through a data mining process, based on an algorithm which integrates a module of neural networks. Besides, a pilot commercial software with the system already integrated is also presented.

2. The refinery platforming unit process

Refineries are composed of several operating units that are used to separate fractions, improve the quality of these fractions and increase the production of higher valued products like gasoline, jet fuel, diesel oil and home heating oil. The function of the refinery is to separate the crude oil into many kinds of petroleum products. This paper pays special attention to platforming unit. This unit is constituted of two basic units: The catalytic reforming or reaction unit and the distillation unit or train distillation.

The catalytic reforming of naphtha is an important refining process that seeks to improve the octane number of gasoline due to a conversion to paraffins and naphthenes in aromatics. The feed to the naphtha reformer is a crude oil fraction from the refinery crude unit with a boiling range between 100 and 180 °C. This process is adiabatically carried out at high temperatures, building up gasoline with a high octane number, LPG, in three reformers: hydrogen, fuel gas and coke. The coke deposits on the spent catalyst surface causing its deactivation. To recover its activation, the catalyst with coke is regenerated after certain running time.

In the first reactor, the major reactions such as dehydrogenation of naphthenes are endothermic and very fast, causing a very sharp temperature drop. For this reason, this process is designed using a set of multiple reactors. Heaters between the reactors allow an adequate reaction temperature level to maintain the catalyst operation.

This process is performed in two different distillation columns (Fig. 1). The separator liquid and a stream, called aromatic LPG from the external platforming unit, feed off the first column, the debutanizer column. This column fractionates the input into two basic products: butane, to the top of the column and a high hydrocarbon flow, also called platformer, to the bottom of the column. Platformer feeds off the debenzenizer, the second distillation unit. Its goal is to obtain a light aromatic flow to the top free to the high hydrocarbon. This stream is fed off the third distillation column that produces benzene and toluene. Benzene and toluene are the important products to the plant. The products are sent to the Morphylane Unit are stored up or sent to the other units of the refinery.

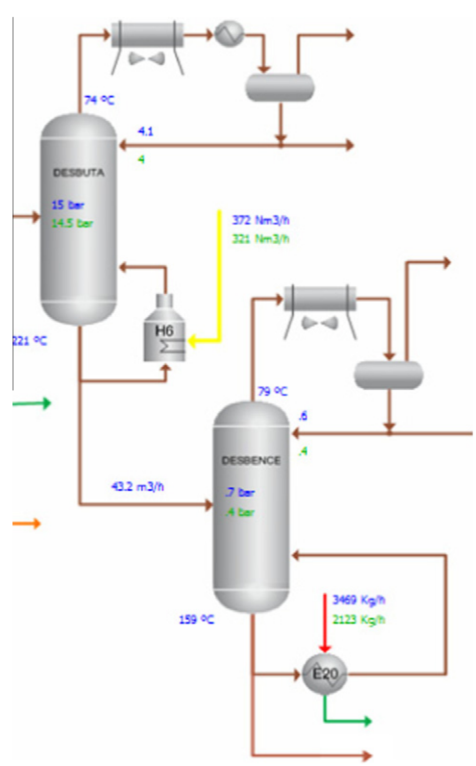

Fig. 1. Flow diagram of the distillation unit.