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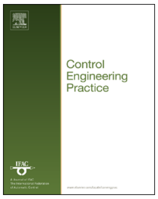

Design of an adaptive predictive control strategy for crude oil atmospheric distillation process

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ABSTRACT

Improving performance and reducing the process operational costs represent a priority for the oil refinement industry. The challenge is given by high energy utilization and strict productivity specifications. Automatic control plays an essential role by providing theoretical and practical tools to overcome these challenges. This paper details the design of an Adaptive Predictive (AP) control strategy for an atmospheric distillation process. The strategy uses AP controllers to face the non-linear and time-varying process dynamics and was defined using classical interaction analysis tools such as the Relative Gain Array (RGA). The AP control strategy was simulated using ADEX and MATLAB simulation environments. The process was simulated using an Aspen Dynamic model. The controller performance is evaluated on a simulator of a crude oil atmospheric distillation process operating in a PEMEX refinery. The simulation results are also compared against a PID-based control strategy, showing an improvement of operational stability.

1. Introduction

Atmospheric distillation of crude oil is the principal refining process of any refinery. It separates the main petroleum products such as naphtha, kerosene, fuel oil and diesel fuel. Because crude oil is a complex and varying mixture of a large number of components, petroleum distillation is generally a hard task marked by a stochastic and multivariable nature, nonlinear behaviors and time varying phenomena (Jones & Pujad, 2006; Luyben, 2006). Reliable advanced control solutions are needed.

This paper presents the design of a decentralized adaptive predictive control strategy for crude oil atmospheric distillation process. The control strategy is based on a particular multi-input single-output (MISO) adaptive predictive (AP) controller, first introduced in Martín-Sánchez (1976a), which allows the controller to successfully regulate the process despite its non-linear and time-varying dynamics. The control architecture is defined after analyzing the interaction between input and output variables based on the relative gain array (RGA) analysis. The proposed control strategy has multiple advantages in process control and parameter adjustment. Furthermore, it is faster and more robust than the Proportional-Integral-Derivative (PID) controller presented in Shinskey (1996).

The AP controllers operation is based on an adaptive predictive model that models the process dynamics and simplifies the control strategy design. The focus of this paper is on the methodology used to determine the most appropriate AP models based on RGA analysis. From a purely theoretical point of view, one centralized multi-input multi-output (MIMO) AP model could adequately meet the control specifications. However, given the computational effort required to adapt an usually large centralized model, an additional interpretation of the relative gain array (Bristol, 1966) pairing technique is used to define a partial decentralized adaptive predictive control strategy. This interpretation allows us to use the relative gains of greater value and to feed other useful relative gains as perturbations in the controller in accordance to the AP control strategy. The adaptive predictive control strategy is simulated using the ADEX (ADEX Control and Optimization platform v2010, ADEX SL, Spain) and Matlab simulation environments. The controllers performance is tested on a crude oil atmospheric distillation process simulator developed in Aspen Plus v7.1 and Aspen Dynamics v7.1. The simulation of the proposed AP strategy results is compared against a PID-based control strategy.

The paper is structured as follows: Sections 2 and 3 present the description and modeling of the atmospheric distillation process. Section 4 describes the fundamentals of AP control; performs the

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RGA analysis, and from this analysis determines the control strategy. In Section 5, the simulation results are presented and compared against a PID based control strategy. In Section 6, we present our conclusions and suggestions for further research.

2. Process description

The crude distillation unit (CDU) is one of the most important processes of any refinery. It is where the atmospheric distillation process takes place. This process accomplishes the first stage of crude oil breakdown and is essential to obtain finished products that are distilled through secondary processes. The process carried out in a generic CDU can be divided into three parts:

1. *Desalting and pre-heating*: before and after desalting, crude oil is pre-heated using other hot streams available in the plant.
2. *Pre-flash*: light components are vaporized in a pre-flash unit (PFU) to reduce the volatile component load at the main furnace.
3. *Atmospheric distillation* (*Topping*): crude oil is heated in a furnace at 350 °C and then is separated into a number of products (such as naphtha, kerosene, light diesel, heavy diesel and a residue) in an atmospheric distillation unit (ADU). This column features side strippers and external coolers (pumparounds) that allow to control the main parameters of the process, such as the column's temperature profile and the temperature of the distilled products.

The CDU studied in this work is a simplified model of a PEMEX distillation process. For simplicity, we only consider two types of Mexican crude oils: Maya and Istmus. Typically, 80% of the distillation process feed is a blend of these two crude oils.

The distilled products derived from the CDU are characterized by distillation curves and boiling ranges. These boiling ranges, together with the grade of gap or overlap between the cut points of two adjacent crude oil fractions, determine the performance of the distillation process. This index is known as gap/overlap of crude oil cuts (Fig. 1). A gap between two adjacent cuts indicates good distillation. On the other hand, an overlap indicates an inefficient cut (Chang & Liu, 2012).

These parameters are used to check if the simulated plant obtains the same quality of refinement as the real plant. Table 1 shows the real range and simulated gap/overlap values from Fig. 1 also the boiling ranges associated with each distilled product that characterize the operating point for the considered process are summarized.

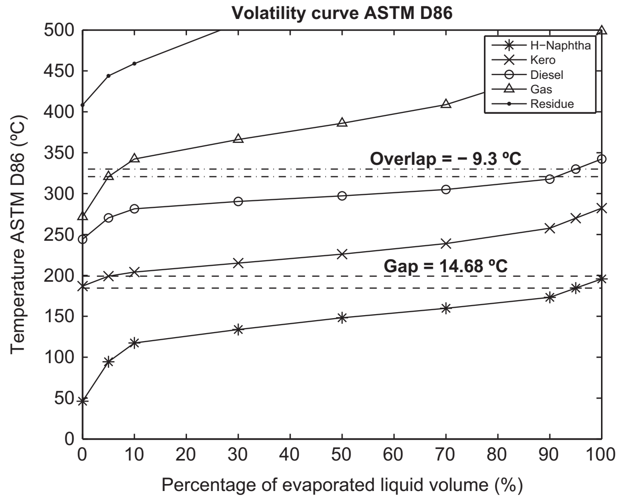

Fig. 1. Volatility curve of the extracted products.

Table 1
Gap/overlap and boiling range evaluation.

Product	Gap/overlap range (°C)	Simulated value	Boiling range (°C)
H-Naph/kero	5–15	14.68	35–150
Kero/diesel	−5–5	0.39	150–240
Diesel/gas	−20–0	−9.30	240–350
Gas/res	−30–−10	−30	390–548

The gap/overlap cannot be measured directly. It is calculated through laboratory tests or through measurements carried out by analyzers that operate in the plant. However, this index is highly related to the product extraction temperatures, which are also valid measurements of the plant's performance and control. In this study we consider a desalted and preheated crude inlet stream. The CDU layout is showed in Fig. 2. To simplify representation, only the furnaces, the distillation columns, the strippers and pumparounds of the ADU are shown. The digits inside of the columns represent the plates, Strippers are labeled with the letter S and pumparounds are labeled with the letters PA followed by their respective number.

The variables shown in the Fig. 2 are considered in the design of the control strategy and are described in Table 2. Both PFU and ADU columns operate at a top pressure of 1.9 atm and at a bottom pressure of 2.8 atm. All thermodynamic parameters can be found in Luyben (2006). The most important simulation parameters are shown in Tables 3–5.

3. Modeling

Modeling of the crude oil mixture is presented in Section 3.1 and the distillation equipment is described in Section 3.2. Atmospheric distillation models and relevant parameters in López, Mahecha, Hoyos, Leonardo Acevedo, and Villamizar (2009), Lekan, Adeniran, and Akinola (2012), Minh (2010), Brooks (1993), and Liu (2012) were considered in this work.

3.1. Crude oil modeling

The physical and chemical characteristics of the oil that is processed by the plant have to be determined to model the crude oil atmospheric distillation process. These characteristics are used to calculate parameters that define the dynamic behavior of the process. Modeling crude oil is different from modeling other chemical compounds. In the distillation processes of most chemical compounds, pure chemical substances are obtained. In crude oil distillation, however, the derivative products that are obtained are complex mixtures. Integrating the characteristics of each component independent from each other unnecessarily increases the complexity of the analysis.

What is usually done is to approximate the crude oil as a reduced group of fictitious components, called pseudo-components. A pseudo-component approximates the physical and chemical characteristics of a sub-group of components that belongs to crude oil. The result is a reduction in the dimensions of the process model.

The approximation of crude oil in pseudo-components is based mainly on the distillation curves. Other characteristics, such as viscosity and sulphur content can be extrapolated with techniques based on the decomposition in pseudo-components. Some crude oil characterization and modeling methodologies, from laboratory trials to pseudo-components calculations, can be found in API (1970), Brooks (1993) and Chang et al. (2012).

In Fig. 3 a conceptual representation of the pseudo-component decomposition is shown. Each pseudo-component is characterized