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Research article

Design and implementation of a control structure for quality products in a crude oil atmospheric distillation column

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ABSTRACT

In recent years, interest for petrochemical processes has been increasing, especially in refinement area. However, the high variability in the dynamic characteristics present in the atmospheric distillation column poses a challenge to obtain quality products. To improve distillates quality in spite of the changes in the input crude oil composition, this paper details a new design of a control strategy in a conventional crude oil distillation plant defined using formal interaction analysis tools. The process dynamic and its control are simulated on Aspen HYSYS® dynamic environment under real operating conditions. The simulation results are compared against a typical control strategy commonly used in crude oil atmospheric distillation columns.

1. Introduction

Oil is the most important primary energy source worldwide. As such, the exhaustion of this raw material serves as a motivation for the oil industry to optimize its processes [1] and to obtain fossil fuel products of higher quality.

In a petroleum refining plant (Fig. 1), crude oil components are separated by the process known as fractional distillation [2]. The process begins when crude oil enters into the atmospheric column, where its products can be obtained in different fractions by increasing the temperature. This is possible due to the fact that each derivative product has a specific boiling point, classified in descending order according to their volatility. In this article, multi-loop PI/PID controllers are implemented in an atmospheric distillation column. As in [3–9], the control strategy is proposed considering PI/PID controllers in order to increase its feasibility to be implemented in refining processes. Each controller is tuned in terms of the desired response to the process specifications, using the Control Station® design tools based on the process open loop step response. Crude distillates are obtained under quality standards in spite of variations in the input load's composition. Also, the tower operates at a constant temperature and fixed pressure, which ensure quality oil fractions. The control structure's design is based on input-output variable interactions, represented in a relative gain array (RGA).

Industrial processes are constantly subject to unplanned process transients (e.g. process uncertainties, external disturbances and sudden malfunctions) which can induce strong variations in plant operating conditions [10]. The proposed control structure aims to improve distillates' quality of the atmospheric distillation column, avoiding relying on the expertise and intuition of its operators and process engineers when dealing with changes in the input crude oil composition. Input crude oil is composed of a mixture of three types of oils, Maya, Isthmus and Olmec, characterized as heavy, medium and light, respectively. The model consists of four stages, preflash, atmospheric, stabilizer and vacuum where different pieces of equipment, such as condensers, reboilers, heat exchangers, distillation columns and strippers, are simulated in steady state and dynamic mode under real operating conditions using Aspen HYSYS® software. Finally, to compare the performance of the developed control strategy, the refinery plant is also simulated under actual control structures commonly used in crude oil distillation plants.

2. Process description

Crude oil is not directly usable. Therefore, separation of mixtures and solutions into its components is one of the fundamental operations in the petrochemical industry. Distillation accomplishes the separation of hydrocarbons in the refining process. This is possible since crude products have different boiling points.

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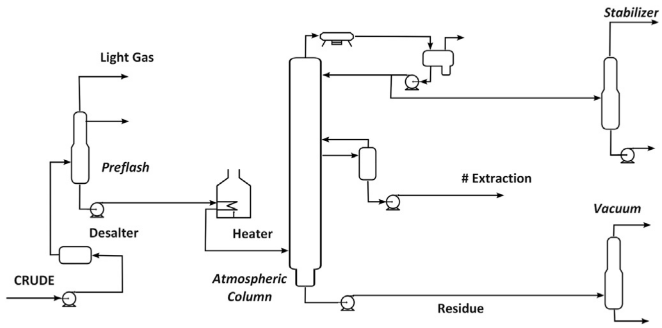

Fig. 1. Conventional refinery.

In the present research, although the proposed control structure is implemented in the crude oil atmospheric distillation column, to present a more realistic conventional refinery plant, the following stages are simulated:

1. *Preflash:* the more volatile components of the crude oil are removed; this in order to avoid weeping in atmospheric distillation column.
2. *Atmospheric:* the crude oil is heated up to 338.4 °C by a furnace. The distillation process operates at a constant pressure of 104 kPa, slightly above atmospheric pressure value. The crude oil is fractionated into five cuts, e.g. naphtha, kerosene, diesel, atmospheric gas oil (AGO) and atmospheric residue. The column has physical components called strippers and pumparounds interacting to control the main distillation process variables such as temperature and pressure profiles.
3. *Stabilizer:* the liquid product (naphtha) is treated through a column to separate gas from oil, operating at a constant pressure of 1 030 kPa. At this stage, combustible gas, LPG (liquefied petroleum gas) and naphtha stabilized are obtained.
4. *Vacuum distillation:* using the non vaporized load of crude oil from the atmospheric stage, the column operates at a constant pressure of 2 kPa. At this complementary operation, the obtained products are top, bottom, light liquid and heavy liquid gas oil (LVGO and HVGO).

The studied refining plant is shown in Fig. 2. The input stream consists of three kinds of crude oils: light, medium and heavy. The entire plant has four distillation columns (preflash, atmospheric, stabilizer and vacuum), modeled by trays. There are three condensers, located on top of the preflash, atmospheric and stabilizer columns. In addition, there is a reboiler in the stabilizer column. The strippers located in the atmospheric column are referred to as *Product-S* while pumparounds are under *PA* legend.

To determine distillation efficiency between two adjacent products, a comparison of ASTM D86 curves is done. The recovery degree of the most volatile components is carried out in the light fraction, whereas the heaviest components are in the heavy fraction. The temperature difference in ASTM D86 curves defines the quality of the separation between two consecutive fractions. This is calculated by subtracting the temperature corresponding to 95% ASTM D86 light fraction (LF) of the corresponding to 5% ASTM D86 of the heavy fraction (HF). If the temperature difference is positive (gap), there is a good separation between adjacent products. On the other hand, if the difference is negative (overlap), the separation between consecutive fractions is poor [11].

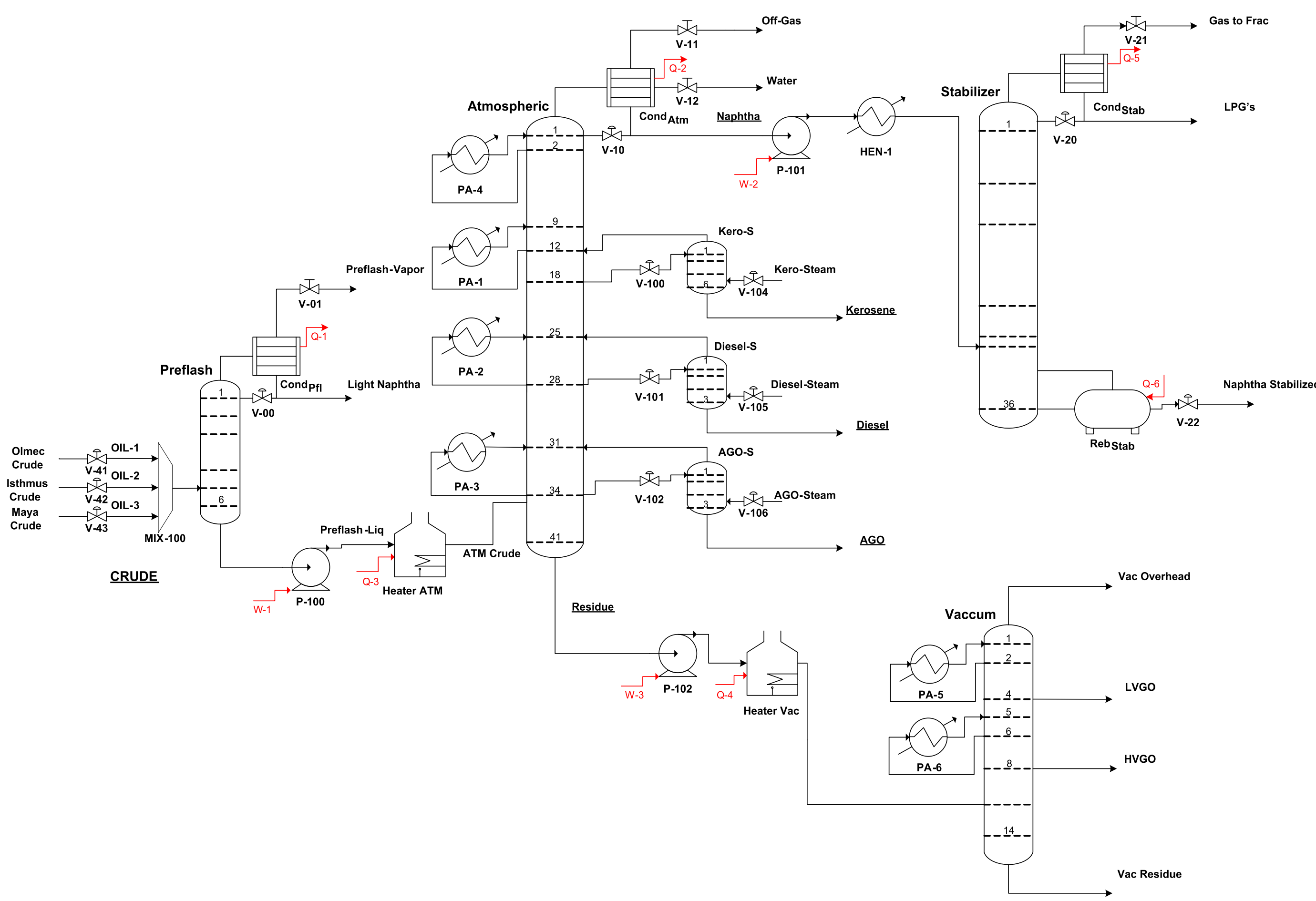

Fig. 2. Process flowsheet.