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Investigation of an alternative operating procedure for fouling management in refinery crude preheat trains

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ABSTRACT

Crude oil atmospheric distillation in petroleum refineries involves a heat exchanger network to heat the crude using hot side streams and pumparounds. This energy integration reduces the furnace load as well as the cold utility consumption, diminishing fuel costs and carbon emissions. During the operation, the effectiveness of the heat exchangers decreases due to fouling. This paper deals with preheat trains composed by multiple parallel branches, where it is investigated an alternative operating policy based on the optimization of stream splits, aiming to manipulate the flow rates according to the fouling status of the existent heat exchangers. The performance of the proposed approach is illustrated by three examples: two networks from the literature and one real network from a Brazilian refinery.

1. Introduction

Petroleum refining usually begins with a first fractionation that takes place in an atmospheric distillation column. Since, the temperature of the column feed must be around 380 °C, hot side streams and pumparounds are employed to heat the crude oil in order to reduce energy consumption. This heating process is accomplished by a heat exchanger network called crude preheat train. However, the target temperature cannot be reached at the network exit, and additional heating must be supplied by a furnace.

During the refinery operation, the thermal surface of preheat exchangers are subjected to fouling. This phenomenon implies a reduction of the energy recovery in the heat exchanger network, which decreases the furnace inlet temperature and forces an increase in fuel consumption, thus diminishing the refinery profitability. In more severe fouling cases, the furnace heating capacity may be reached and the crude throughput must be reduced. Considering also environmental aspects, fouling brings an increase in CO_2 emissions, because of the higher furnace load.

Due to the importance of this heating process, several papers have been published investigating different aspects of the problem, such as: monitoring of the heat exchanger network for fouling status diagnosis [1–3], prediction of fouling rates [4–6], analysis of the fouling impact on the design/retrofit problems [7,8] and cleaning schedule optimization [9–14]. Regarding schedule optimization, the main objective is to develop an algorithm for the identification of the best set of time instants for heat exchanger cleaning. The cleaning action involves a tradeoff: it brings a reduction of fuel consumption but implies extra costs (manpower, cranes, chemicals, etc.) and, during the cleaning procedure, the energy recovery is more penalized, because the respective heat exchanger is bypassed. Considering that a typical preheat train may have up to 60 heat exchangers [15], the resultant problem is considerably complex. An important trend in the literature to solve this problem involves the use of mathematical programming (mixed-integer nonlinear programming [9,10] or mixed-integer linear programming [11–13]).

Focusing on preheat train networks composed by multiple parallel branches, this paper proposes a different investigation, exploring the analysis of stream splits. If each individual branch presents different fouling levels, due to distinct previous cleaning schedules, dissimilarities in the flowsheet of the branches or differences in the operational history, a potential interesting approach may be to redistribute the flow rate of the hot and cold streams among the branches according to their particular thermal effectiveness. The exploration of stream split optimization was considered in Athier et al. [16], but it was limited to the context of the problem of heat exchanger network synthesis.

In order to quantify the impact of the proposed operating procedure, three examples are analyzed in this paper, two networks based on the literature and one network from a Brazilian refinery.

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Nomenclature

$\underline{A}$	matrix of coefficients of the network flow model
A	heat exchanger surface area (m^2)
$\underline{b}$	vector of the network flow model
C	heat capacity flow rate (W/K)
$\underline{C}$	matrix of coefficients of the network energy model
C_R	ratio of heat capacity flow rates
$\underline{d}$	vector of the network energy model
h	film coefficient (W/m^2 K)
m	mass flow rate (kg/s)
T	temperature (°C)
T_{fn}	inlet furnace temperature (°C)
U	overall heat transfer coefficient (W/m^2 K)
$\underline{x}$	variable vector of the network flow model
y	binary parameter related to heat capacity flow rates
$\underline{z}$	variable vector of the network energy model

Greek symbols

α	split fraction
ε	heat exchanger effectiveness
ϕ	decision variable of the optimization problem

Subscripts

base	base case
i	inlet
o	outlet
c	cold stream
h	hot stream
t	split node index

2. Optimization problem

The structure of the crude preheat trains analyzed involves two or more parallel branches of heat exchangers. In this case, the distribution of the flow rates of the hot and cold streams among different branches can be manipulated to maximize the inlet furnace temperature. Fig. 1 depicts a simplified representation of a typical network with the proposed characteristics, where there are two cold stream splits and three hot stream splits.

The representation of the optimization problem corresponds to:

$$\begin{cases} \max & T_{fn}(\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_{NSP}) \\ \text{subject to} & \\ 0 \leqslant \alpha_t \leqslant 1 & \end{cases} \quad (1)$$

where T_{fn} is the inlet furnace temperature and α_t is the split fraction of the stream related to splitter t. The subscript NSP represents the number of stream splits that can be manipulated in the network Aiming to eliminate the problem constraints, a variable transformation is applied, where the original split fractions are substituted by new decision variables, ϕ (similar to [17]):

$$\alpha = \frac{\exp(\phi)}{\exp(\phi) + 1} \quad (2)$$

This approach results in an unconstrained optimization problem, solved in this paper using the simplex method for nonlinear optimization [18]:

$$\begin{cases} \max & T_{fn}(\phi_1, \phi_2, \phi_3, \ldots, \phi_{NSP}) \\ \phi \in \Re & \end{cases} \quad (3)$$

The relation between the set of split fractions and the inlet furnace temperature is given by a heat exchanger network model. Each evaluation of the objective function demands a steady-state simulation run of the network, following the scheme illustrated in Fig. 2, where network parameters represent flowsheet connections, surface area of the heat exchangers, inlet temperatures and flow rates, etc. The model equations adopted in this paper are presented in the next section.

3. Steady-state heat exchanger network model

A heat exchanger network can be described as a collection of heat exchangers, mixers and splitters interconnected for promoting heat transfer between hot and cold streams. Mass and energy balances together with ε-NTU equations compose the employed network model.

3.1. Heat exchangers

The steady-state flow in a heat exchanger is represented by mass balance equations:

$$m_{h,i} - m_{h,o} = 0 \quad (4)$$
$$m_{c,i} - m_{c,o} = 0 \quad (5)$$

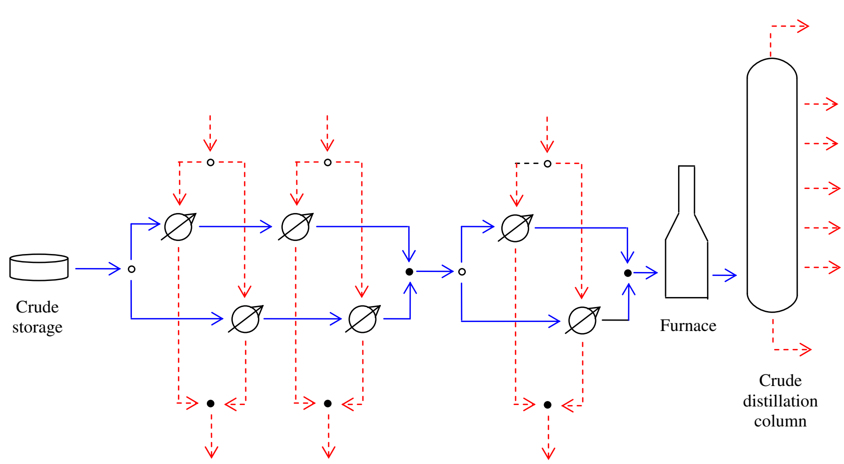

Fig. 1. Simplified configuration of a typical multi-branch preheat train.