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Strategy of changing cracking furnace feedstock based on improved group search optimization☆

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ABSTRACT

The scheduling process of cracking furnace feedstock is important in an ethylene plant. In this paper it is described as a constraint optimization problem. The constraints consist of the cycle of operation, maximum tube metal temperature, process time of each feedstock, and flow rate. A modified group search optimizer is proposed to deal with the optimization problem. Double fitness values are defined for every group. First, the factor of penalty function should be changed adaptively by the ratio of feasible and general solutions. Second, the "excellent" infeasible solution should be retained to guide the search. Some benchmark functions are used to evaluate the new algorithm. Finally, the proposed algorithm is used to optimize the scheduling process of cracking furnace feedstock. And the optimizing result is obtained.

1. Introduction

Ethylene (C_2H_4) is an important chemical raw material. Ethylene industry is the cornerstone of the petrochemical industry. Ethylene production indicates the level of petrochemical development [1]. The ethylene cracking furnace is the key equipment in the ethylene industry and consumes as much as 50% to 60% energy of the plant. Therefore, optimizing and scheduling of cracking furnace are important because of high benefit [2,3].

Studies on cracking furnace scheduling mainly focus on the operation and optimization. Edwin and Balchen used dynamic optimization to determine the batch processing time and time-dependent operation trajectory of a cracking furnace [4]. For multi-furnace scheduling, Jain and Grossmann developed a mixed-integer nonlinear programming (MINLP) model for cyclic scheduling that considers coil coking [5]. Schulz *et al.* extended the MINLP model to ethane-fed ethylene plants with more focus on recycled ethane [6]. A discrete-time MINLP model was recently developed to optimize cyclic furnace shutdowns and downstream separation units [7]. Lim *et al.* integrated a neural network-based cracking simulation model into scheduling. The dynamic data of ethylene and propylene yields, tube metal temperature (TMT), and pressure drop could be obtained and used in the scheduling decisions [8].

However, feedstock scheduling in one operation cycle has not been considered yet. In many ethylene plants, the cracking furnace cracks a feedstock first, and then switches to others. The switch time and feed flow rate changing will decide the operating cycle and product yields.

To improve the benefit of cracking furnace, a model describing the scheduling process of feedstock is constructed in this study. The model considers the following factors: operating condition of each feedstock, operating cycle, maximum TMT, and process time of each feedstock. The goal is to maximize the benefit in an operating cycle. Software Coilsim1D is used to simulate the cracking furnace [9,10]. The cracking reaction is simulated with series complex free radical reactions.

A modified group search optimizer (GSO) is proposed to solve the nonlinear constraint problem. This method searches for the smaller feasible region by adaptive penalty function and retains the "excellent" infeasible solution to improve the optimization accuracy. The algorithm is evaluated in some numeral simulations. Finally, the algorithm is used to the scheduling process of feedstock.

2. Description of the Ethylene Cracking Furnace

The structure of a typical cracking furnace is shown in Fig. 1. The feeds (gas or liquid) and dilution stream are preheated in the convection section to form a mixture, gasified to the cracking temperature [11,12]. The cracking reaction mainly occurs in the radiant section at a high temperature. Meanwhile, the coil of the radiant section and the transfer line exchange are coked [13]. The mixture gas in the radiant

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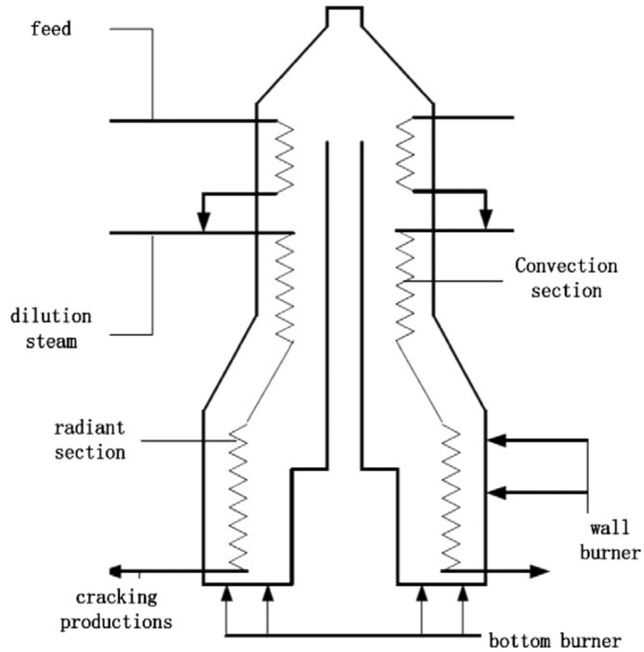

Fig. 1. Structure of the cracking furnace.

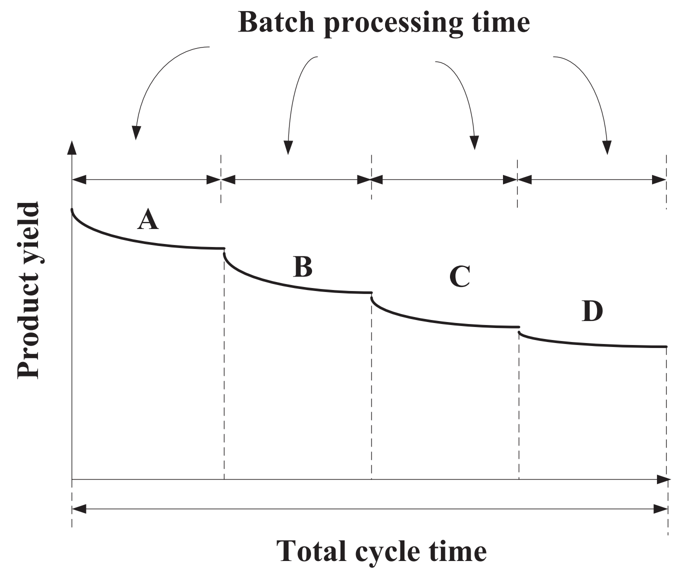

Fig. 2. Demonstration for cyclic scheduling of ethylene cracking furnaces.

section is cracked into C_2H_4, C_3H_6, C_2H_6 and other by-products, such as cracked gasoline.

During the cracking process, the growing coke on the inner surface of the coil and transfer line exchange reduces the efficiency of heat transfer, and consequently, increases TMT and export temperature of transfer line exchange. It also reduces the inner diameter and increases the pressure drop, decreasing the selectivity toward cracking. Therefore, the cracking furnace should be shut down from 50 days to 90 days to decoke.

Based on its density, the feedstock can be divided into two types, light and heavy ones. The light feedstock used in ethylene plants includes liquefied petroleum gas (LPG), naphtha (NAP), and light naphtha, while the heavy cracking feedstock involves atmospheric gasoline oil and heavy vacuum gas oil (HVGO). Two kinds of feedstock are usually cracked in one operating cycle. The attribute of feedstock has a great effect on the yield of product and coking rate. For instance, the coking rate of light feedstock is slower than that of heavy feedstock. Normally, the yield of ethylene and propylene of heavy feedstock is higher than that of light feedstock. Compared with light feedstock, heavy feedstock is cheaper.

3. Statement f Problem

We assume that i types of feeds ($i = 1, 2, \ldots, NF$) are present in a cycle in a cracking furnace. The cracking gas consists of j types of components ($j = 1, 2, \ldots, NC$). The switching time from one feedstock to another is very short compared with the operation cycle, so it is ignored. The total cycle time is divided into k batch time ($k = 1, 2, 3, \ldots, NB$). The process time of the ith feedstock is $t_{i,k}$. The flow rate of the ith feedstock is denoted by F_i and $F_i \in [Flo_i, Fup_i]$, the lower and upper limits. The problem is how to schedule the type of the feedstock to maximize the profit considering $t_{i,k}$ and total cycle time T_{cycle}.

Fig. 2 shows the cyclic scheduling of one furnace, with batch processing time and T_{cycle} demonstrated. The four feeds designated as A, B, C and D are allocated into different batch slots for processing.

3.1. Cracking reaction model

Cracking reaction is very complex and the number of cracking products is more than 100. Many processing variables cannot be measured directly, such as the yield of cracking product, while some gas phase compositions, such as CH_4, C_2H_4, C_2H_6, C_3H_8 and C_3H_6, can be measured by a gas chromatograph. Cracking furnaces are operated in steady state. The operating variable cannot be changed in a wide scope, so it is impossible to obtain the optimization model directly from the operating data. In the schedule optimization of feedstock, an appropriate cracker model is very important.

Coilsim1D is a new proprietary model for predicting product yields [14], which consists of the extensive reaction network for steam cracking of hydrocarbons. This fundamental approach produces accurate simulation results for different types of feedstock.

In order to simulate cracking furnaces appropriately, several parameters of Coilsim1D model must be corrected based on the parameters and operating data of cracking furnace, such as the coil size and material, cracking severity [15]. After correcting, the output of cracker model is similar with the furnace output. Then the operation variables can be changed in a wide scope and the model can simulate the thickness of coke in the inner coil, so the coking data can be recorded precisely during the feedstock switchover.

3.2. Objective function

The objective of scheduling optimization is to maximize profitability. The net profit in a cycle is calculated by

$$P_{\text{net}-\text{profit}} = P_{\text{income}} - P_{\text{raw}-\text{material}} - P_{\text{operation}} \quad (1)$$

where $P_{\text{net}\,-\,\text{profit}}$ is the net profit, P_{income} is the total income from various products, $P_{\text{raw}\,-\,\text{material}}$ is the cost of all raw materials, and $\mathrm{P}_{\text{operation}}$ is the operational cost.

Primary product yields, such as hydrogen, benzene, ethylene, propylene, and butadiene, are calculated by Coilsim1D. NAP and HVGO are used as the feedstock. The parameters of cracking NAP and HVGO are respectively listed in Tables 1 and 2. The yields of products with operating time are demonstrated in Figs. 3–10. The profile of each component can be represented with an exponential model

$$y_{i,j} = c_{i,j} + a_{i,j} e^{b_{i,j} t} \quad (2)$$

where $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ are the parameters of the ith feedstock ($i = 1, 2, \ldots, NF$) and the jth product ($j = 1, 2, \ldots, NC$).