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Investigation of coil outlet temperature effect on the performance of naphtha cracking furnace

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ABSTRACT

In this study, liquid furnace has been investigated to find out the reason of over-cracking which results in excessive tar and coke formation so that the furnace run length is decreased. For this purpose, a one-dimensional mathematical model is used to analyze the furnace temperature profile. In addition, inlet feedstocks and outlet gas products of furnace have been studied. The results obtained from the simulation demonstrate differences between modeled coil outlet temperature and cracking severity with those of experimental data. For overcoming this problem, furnace temperature were sufficiently reduced with the purpose of reaching constant cracking severity at 0.5. Correction of the coil outlet temperature led to significant increase in cracking severity, propylene production, furnace capacity and run length while gasoline production and number of decoke cycles decreased.

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Keywords: Naphtha; Thermal cracking; Mathematical modeling; Over-cracking; Furnace run length

1. Introduction

Cracking is a process whereby heavy hydrocarbons are broken down into light and useful hydrocarbons such as paraffin and olefin. Different types of cracking applied in petroleum and petrochemical industries are:

- **Steam cracking:** In steam cracking, a gaseous or liquid hydrocarbon feedstock like naphtha, LPG or ethane is thermally cracked through the use of steam without the presence of oxygen. It is the principal industrial method for producing the lighter olefins such as ethylene and propylene.
- **Thermal cracking or pyrolysis:** This type is the cracking of heavy residues under severe thermal conditions. Thermal cracking is currently used to upgrade very heavy fractions and produce valuable light fractions and feedstocks for the petrochemical industry.

- **Catalytic cracking:** this process involves the presence of acid catalysts (usually solid acids such as silica-alumina and zeolites) (Xu et al., 2011; Choudhary and Mulla, 2001).
- **Hydrocracking:** Hydrocracking takes place on catalyst in the presence of elevated partial pressure of hydrogen gas. According to the reaction conditions (temperature, pressure and catalyst activity), products of this process vary from ethane and LPG to heavier hydrocarbons which are all saturated hydrocarbons.

In this case, steam thermal cracking of naphtha has been studied. Steam cracking of naphtha is applied to olefins production with three main products including ethylene, propylene and butadiene. Propylene has been the fastest growing of the three main olefins, mainly because of the strong demand for polypropylene, acrylonitrile (ACN), oxo alcohols, propylene oxide, cumene and acrylic acid are other important derivatives of propylene (Xu et al., 2012). Due to the increase

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in demand for propylene, alternative ways for production of propylene are available such as fluid catalytic cracking (FCC) (Wang et al., 2008), methanol-to-olefins (MTO) and methanol-to-propylene (MTP) (Mei et al., 2008). However, nowadays propylene is mainly produced as a co-product of ethylene via steam cracking of naphtha (Xu et al., 2012). Steam cracking is an endothermic and energy intensive process which takes place in pyrolysis furnace (Choudhary and Mulla, 2001).

The furnaces are the most important and expensive pieces of equipment in the unit and they are considered as the heart of the ethylene plant. Each furnace is composed of convection and radiation sections and reactions take place in the second section of pyrolysis coils (Maciel Filho and Sugaya, 2001). The pyrolysis yield pattern is strongly affected by the hydrocarbon partial pressure, the temperature profile, and the residence time. Moreover, moderation of radiant heat flux ensures the coke formation rate is kept to a minimum. By carefully optimizing these parameters, the best yield pattern are obtained while retaining a long continuous on-stream time between successive decoking operations.

For developing the cracking severity parameter, some criteria exist such as: the coil outlet temperature, the extent of feed gasification, product yield ratio and the rate of decomposition of model components (Shu and Ross, 1982). In commercial units, only easily accessible exit yields and parameters can be used as a severity factor (Ghashghaee and Karimzadeh, 2011). In this study, the propylene/ethylene mass ratio (P/E) has been proposed as the best index to calculate the severity for optimizing the furnace performance since measuring the amount of propylene and ethylene with chromatography analyzing of furnace effluent gas is so easy.

In furnaces, temperature is one of the most important process variable since it influences not only the pyrolysis reaction, but also determines the mechanical limits for furnace design. At a fixed residence time, higher temperatures will increase the depth of cracking and ethylene yield, up to a point beyond which over-cracking and product degradation occur, leading to excessive carbon and polymer formation.

Typical run length (the period between two successive decoking periods) of cracking furnaces is 30–90 days depending on the feed, operating conditions and the reactor types (Shokrollahi Yancheshmeh et al., 2013). During this run length and endothermic cracking process, a large amount of coke deposits on the inner walls of the tubular cracking reactor (Choudhary and Mulla, 2001). Coke formation leads to serious problems, such as reduction in olefin selectivity as a consequence of increased pressure drop in the cracking coil, elimination of one or more products at the end of the period (Edwin and Balchen, 2001), decrease in wall heat transfer in reactor and at last it reduces the life of reactor tubes (Choudhary and Mulla, 2001). When the skin temperature of cracking coil reaches its maximum allowable value, decoking must be carried out via a mixture of air and steam (Shokrollahi Yancheshmeh et al., 2013; Edwin and Balchen, 2001; Heynderickx et al., 2006; Jianxin et al., 2012). The furnace must first be taken out of production in decoking procedure and then a flow of steam or a steam/air mixture is passed through the furnace coils. It converts the hard solid carbon layer to carbon monoxide and carbon dioxide. Once this reaction is complete, the furnace can be returned to service.

The main effects of thermal cracking plant and its optimization have been investigated in various cases. Basu and Kunzru (1992) reported the effect of temperature, residence time and weight ratio of steam to naphtha on the plant.

Table 1 – Design feed of liquid furnace.

Feedstock	Design flow rate (kg/h)	Mass fraction
Light end	21,645	0.4312
Raffinate	11,995	0.2390
LPG	2620	0.0522
C ₅ cut	1736	0.0346
C ₅ ⁺	2873	0.0572
Propane recycle	937	0.0187
C ₄ cut recycle	8390	0.1671

With increasing temperature, yields of methane and ethylene increased whereas the yield of propylene passes through maxima. Bajus et al. (1980) has studied the effect of residence time, the temperature, the reactor material, the ratio of steam to hydrocarbon and the sulfur compounds presence on products yields and coke formation. Pinter et al. (2004) have indicated that the optimal yields of ethylene and propylene can be achieved at intermediate pyrolysis temperatures and residence times.

2. Process description

The cracking plant is one of the plants composing the 10th olefin complex receiving its feed from other complexes. Liquid furnaces are designed to crack liquid feedstock and recycled propane and butane.

For supplying the liquid furnaces feed, the C₅⁺ feed, the C₅ cut, raffinate and light ends are mixed and sent to the liquid surge feed drum. The mixture is pump out and then mixed with the LPG feedstock. The propane and C₄ cut recycles are mixed to the other liquid feeds at the discharge of the pump. The liquid feedstock is then preheated before being sent to the furnaces. Feedstocks specifications are given in Table 1.

The main sections of a liquid furnace are described below.

2.1. Convection section

Since the radiant coil operates at high temperature, the residual part of the fired duty is recovered in the furnace convection section. At each furnace, the feed and dilution steam are heated by flue gas in their respective convection banks prior to mixing. The purpose of these convection banks is to heat the feed/steam mixture to the required radiant coil inlet temperature.

2.2. Radiant section

As the feed/steam mixture enters the radiant coil, it is rapidly heated to a temperature at which pyrolysis is initiated. Thermal cracking is sustained over the radiant coil by the continuous supply of heat from the radiant gases surrounding the coil. The cracked gas exits the radiant section, flowing upward through the roof of the firebox.

2.3. Temperature quench system

In order to stop the reaction at the radiant coil outlet, the pyrolysis product is rapidly cooled, or quenched, in the transfer line exchanger (TLE) by several hundred degrees in a time interval of milliseconds.

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