ON APPLYING ADVANCED PROCESS CONTROL FOR FCCU IN A PETROLEUM REFINERY

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Abstract

Fluid catalytic cracking unit (FCCU) is difficult for modeling and control due to the large process scale, complicated hydro-dynamics and complex kinetics of both cracking and coke burning reactions, highly heat and material interactions in its reactor-regenerator, main fractionator and absorber-stripper-stabilizer sections, and frequently changes of feed rate and feed composition. Since FCCU is capable of converting large quantities of heavy feed into valuable lighter products, any improvement in design, operation and control can result in substantial economics benefits. A commercial advanced process control (APC) suite was developed and implemented in a 1.8 million tons per year FCCU at Zhenhai Refinery of SINOPEC to help improve process operation and achieve process economics. In this paper the key points of APC technique and its FCCU Applications are highlighted with emphasis on discussion of FCCU control strategy design. Commercial results from the industrial implementation are also shown.

Keywords: FCCU, Advanced process control, Predictive control

1 Introduction

FCCU is one of the most important units in the petroleum refining industry for the conversion of heavy gas oil to gasoline and light hydrocarbons. With the escalating price of crude oil and increasingly heavier FCC feedstock, more and more refineries in China try to increase the blending ratio of residue in FCCU feedstock to improve the secondary processing benefits. Since the performance of the FCC units plays a major role on the overall economics of a refinery, there is a strong demand for advanced process control and real-time optimization with higher control quality to meet the challenges imposed by the growing technological and market competition.

The FCCU at Zhenhai refinery of SINOPEC was originally installed in 1978, designed for processing 1.2 million tons of VGO (vacuum gas oil) per year. It was expanded and revamped in 1997 and 2004 respectively. Based upon the special features of the two-stage riser FCC process, it has a handling capability of 1.8 million tons per year of the mixtures of VGO, CGO (delayed coker gas oil) and residual oil of the VDU (vacuum distillation unit), aiming at producing more propylene and improving gasoline quality. The APC system was implemented on the FCCU in 2005, using APC-Adcon and APC-Sensor technologies from Zhejiang Supcon Software Co., Ltd. It consisted of four multivariable controllers, covering reactor-regenerator section, main fractionator section, and absorber-stripper-stabilizer section, with seven soft sensors for catalyst circulation rate, product qualities of LPG (liquefied petroleum gas), stabilized gasoline, diesel and fuel gas. The main benefits of this application came from steady, safe and reliable FCCU operation while satisfying operating constraints, improvement of quantities and qualities of FCCU products, and continually maximization of residual oil feed against the available temperature limit of the second regenerator.

The paper is organized as follows. In Section 2 the FCC process and control requirements are briefly described. In Section 3 the APC structure and some important issues of the controllers are discussed. In Section 4 industrial application results are presented. The contrastive application results corresponding to conventional control and APC are given. The paper is finally concluded in Section 5.

2 FCC Process Description and Control Requirements

The FCCU at Zhenhai refinery was designed to convert low value mixtures of heavy distillate oil such as wax distillate and residual oil into high value light products, e.g. gasoline, light diesel, etc. by cracking the oil at high temperature in the presence of a catalyst. It consists of reactor-regenerator, main fractionator, absorber-stripper-stabilizer, main air blower and wet gas compressor, etc.

The catalyst type was chosen to maximize propylene based upon the special features of the two-stage riser FCC process. Reaction products and spent catalyst discharge in the reactor whose main function is to disengage the catalyst particles from the vapor product through a battery of cyclones. Catalyst regeneration is achieved by burning off the coke deposit in fluidized bed inside the two cascade regenerators. Catalyst in catalyst circulation rises from riser to reactor and from there flows to regenerator by stripper and stand-pipe and then rises up again from riser to reactor. Steam turbine driven air blowers supplies the oxygen to burn the coke deposit. The main fractionator separates the reactor products into bottoms slurry oil, cycle oil, light diesel, raw gasoline, and wet gas stream is separated in the absorber-stripper-stabilizer section. A simplified flow diagram of the FCCU is shown in Fig.1.

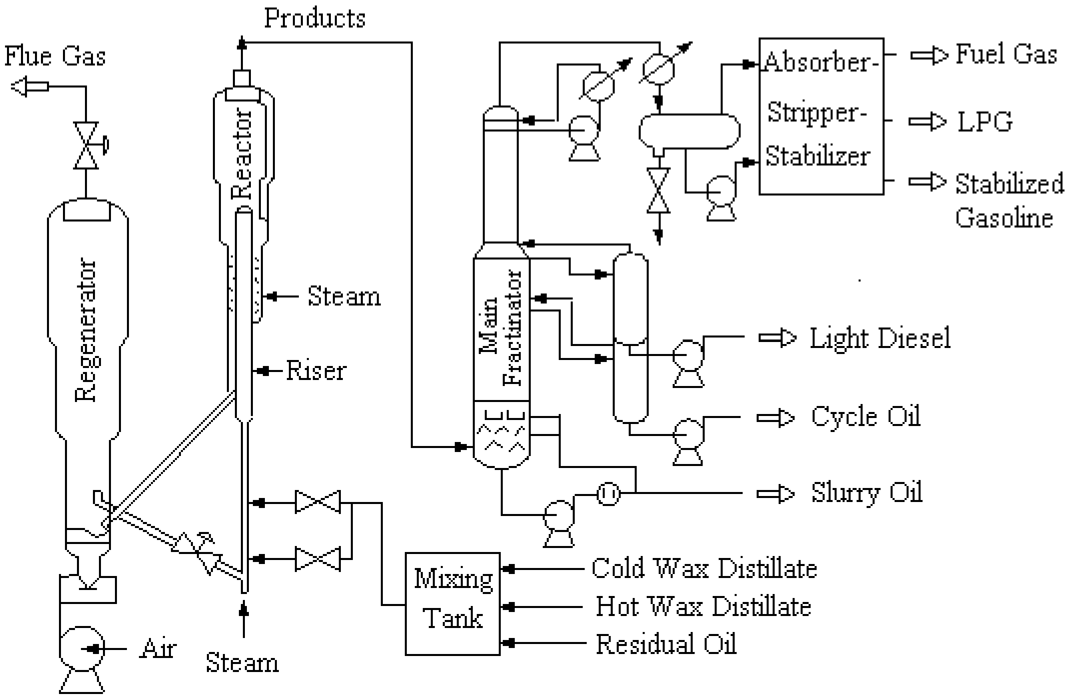

Fig.1 Simplified flow diagram of FCCU

The dynamics of the unit are complex, which consists of multiple sophisticated chemical and physical processes. The production goal is to maintain safe and reliable operation, to produce the cracked light products with cost minimization, i.e. improving the process operating stability, maximizing the process throughput and desirable products yield, improving the product quality, and minimizing energy consumption which in turn maximize the profit. From process control point of view, FCCU can be considered as a high dimension, highly nonlinear, interconnected, complex system. Furthermore, the unmeasurable, uncontrollable factors (such as feedstock and catalyst properties) and process constraints continuously disturb the unit making process control and optimization difficult.

The objective of the reactor-regenerator control is, to attain the best possible operation and gain most profits at large throughputs of residual oil and low energy consumption. It is sure that the process should be run at its optimized zones near constraints. The major independent reaction variables in the FCCU, operating in the maximum gasoline mode are: reactor temperature, combined feed rate, combined feed (feed preheat) temperature, reactor pressure, catalyst activity. The dependent variables, on the other hand, are responsive to changes in the independent variables. These include: the catalyst circulation rate, the catalyst/oil ratio, the regenerator temperature, and conversion.

The purpose of the main fractionator is to de-superheat and recover vapor. The hot-product vapors from the reactor flow into the main fractionator; these vapors enter the column near the base. The main function of the fractionator is to condense and separate the reaction products. The operation of the main column is similar to a crude tower but with two differences. First, the effluent vapors must be cooled before any fractionation begins. Second, large quantities of gases will go overhead with the un-stabilized gasoline for further separation.

Aside from slurry oil product and wet gas, the main fractionator has three side cuts: raw gasoline, light diesel and cycle oil. The recovered heat from the main fractionator is used to preheat the fresh feed, generate steam, and serve as a heating medium for re-boilers of the absorber-stripper-stabilizer section.

The control objectives in the absorber-stripper-stabilizer section are to maintain distillate composition at set point in the presence of disturbance. These disturbances may be characterized due to (i) loads, (ii) changes in cooling and heating medium supply condition and (iii) equipment fouling. Any distillation control system we design must be able to cope with the types of disturbances in the feed and in the supply conditions of the heat exchangers.

3 APC System Design

A hierarchical advanced process control and optimization system is developed as in shown in Fig 2, which integrates 4 sub-controllers based on model predictive control strategy and 1 intelligent controller for maximization of residual oil, 7 soft-sensors, by using APC-Adcon and APC-Sensor respectively. The system communicates with Honeywell TPS DCS by APP NODE.

There are more than ten operating variables to test the operation performance of the FCCU, mainly corresponding to product qualities, desirable products yield and energy consumption. The FCCU needs to be maintained close to optimal operating conditions, however, it's difficult to achieve favorable regulatory loop control performance all the time. Therefore, model predictive control (MPC) can be used to improve control performance with a reduction in the variability of the controlled variables through information gathering, process analysis, and constrained multivariable optimization.

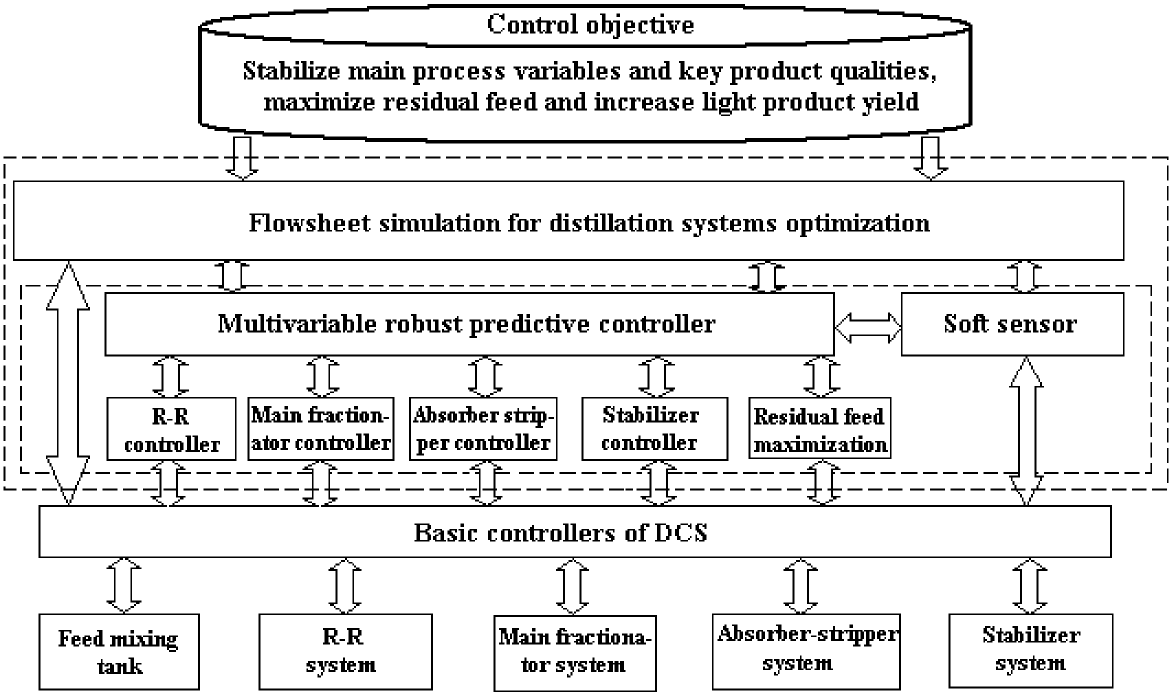

Fig 2 Advanced process control system hierarchy for RFCCU

3.1 Multivariable predictive controller

The advanced process control package of the FCCU at Zhenhai refinery comprises four sub-controllers and one intelligent controller. In the reactor-regenerator sub-controller, second regenerator temperature, feed tank level, second regenerator excess O2, and differential pressure of regenerated catalyst slide valve are the key controlled variables, combustion air flow residual feed flow, hot VGO flow, and combined flow of cold VGO, CGO and recycle oil are manipulated variables. In addition, there are eight disturbance variables. In main fractionator sub-controller, there are six controlled variables such as all product quality variables, ten manipulated variables included reactor riser temperature, and six disturbance variables. In the absorber-stripper-stabilizer section, we adopted two sub-controllers. The absorber-stripper sub-controller has five controlled variables, four manipulated variables and three disturbance variables, and the stabilizer has five controlled variables, three manipulated variables and three disturbance variables. The objective of the constraint controller is to maximize residual feed flow against the second regenerator metallurgical high temperature limit.

3.2 Soft sensor

In order to support the APC system of the unit, using APC-Sensor software, by incorporating principal models with fuzzy neural network, we developed 7 soft sensors to infer the key process variable values for process control and monitoring. which are: catalyst circulation, product properties for the main fractionator and the absorber-stripper-stabilizer such as the end point for raw gasoline, 95% point for LCO, the C2 and C5 concentrations in the LPG, the C3 concentration in fuel gas, and RVP for the stabilized gasoline, etc.

4 Industrial Application Results

After the implementation of the APC system, the deviation of the main process variables became one half of that before APC implementation, as shown in Fig 3 (TI521, LIC401, LI405, AND TI405 are the 2nd regenerator's temperature, level of separator of oil and gas, stripper bottom level, and stripper bottom temperature). The standard deviations of the main products qualities before and after APC are shown in Table 1.

As a result, The over economical merit from this implementation is approximately over four million RMB Yuan by increasing the production of light product, improving product quality, and minimizing operating cost. Industrial application results show that the APC software can maintain the best operation for a long time and realize ultimate operating potential of the RFCCU by reducing the consumption of energy, improving product quality, and minimizing operating cost.

5 Conclusions

This paper introduces the industrial application of APC for the FCCU in Zhenhai Refinery. The APC system is developed to deal with the constrained multivariable control of the reactor-regenerator, main fractionator, and absorber-stripper-stabilizer sections on-line. Several soft sensors are developed to implement direct control of product quality. It can be concluded from the control application example of the FCCU that along with continued implementation of model predictive control, well understanding of chemical engineering principle will help control the process subject to operating constraints, integrating flowsheet simulation and soft sensor technology improves operational effectiveness from the individual process level to the online optimization.

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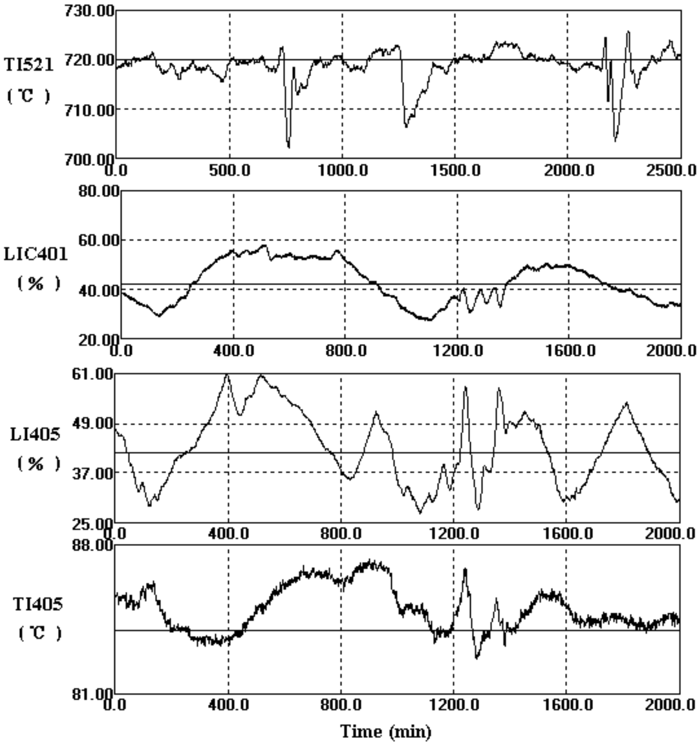
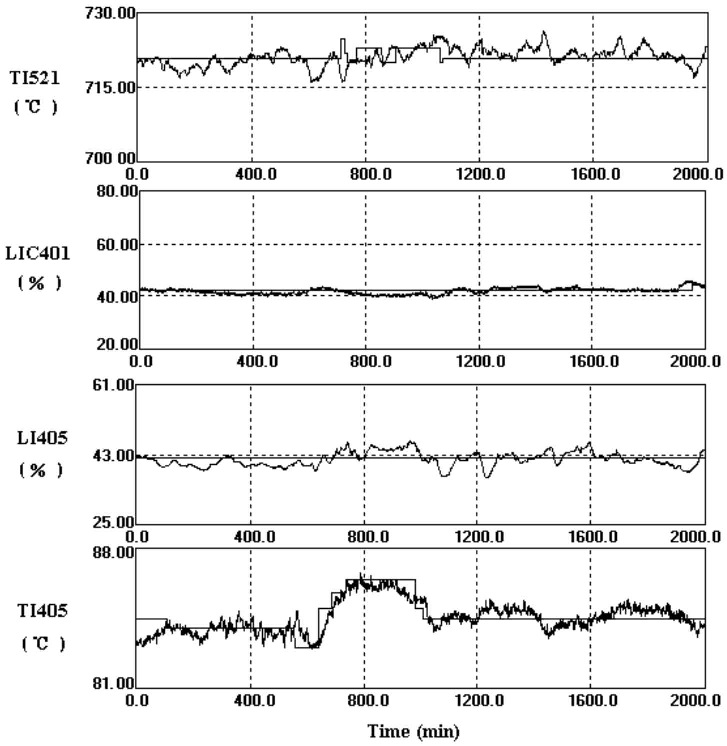


(a) before APC implementation



(b) after APC implementation

Fig 3 Comparison of process control performance under APC and classical control

Table 1. Comparison of standard deviations of the main products qualities

standard deviations	Before APC	After APC	Reduction
end point for raw gasoline	2.57	4.18	38.52%
95% point for LCO	5.79	7.64	24.21%
C_3 concentration in fuel gas	0.368	0.514	28.40%
C_2 concentrations in the LPG	0.011	0.035	68.57%
C_5 concentrations in the LPG	0.167	0.21	20.48%
RVP for stabilized gasoline	1.3	1.58	17.72%