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Application of Plantwide Control Strategy to the Catalytic Cracking Process

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Abstract

This paper presents an application of plantwide control strategy for a complex process, like catalytic cracking process. The plantwide control strategy assists the engineer in determining how to choose the best manipulated, controlled and measured variables in the plant, when is using advanced control techniques such MPC. The result of applying plantwide control to catalytic cracking process is a hierarchical control structure, which is organized on three levels, with two advanced control techniques for the second level. From economic point of view, the development and the implementation a hierarchical control structure for the catalytic cracking process is leading to increase plant efficiency.

Keywords: plantwide control, hierarchical control, fluid catalytic cracking

1. Introduction

The fluid catalytic cracking is an important process in refineries for transforming heavy hydrocarbons in to more valuable lighter products. This process contains three main components: riser, striper and regenerator, see fig 1. In the riser, hot catalyst is brought in contact with the vaporized feedstock and cracking reaction takes place. The striper, located at the reactor top, being formed of a cyclones system for the separation of the feedstock and the reactor products in the gaseous phase, from the catalyst particles. The regenerator, in which the coke deposited on the catalyst during the cracking reaction, is burnt off to regenerate the catalyst. The regenerated catalyst is circulated back to the riser while the cracked products are sent to the fractionators for recovery.

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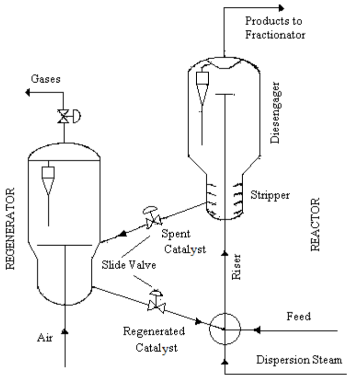
From automatic control point of view, the catalytic cracking process is a multivariable system, with a nonlinear behaviour and strong interactions between variables of the process and between control loops. The requirements to control structure associated to the catalytic process are:

- safety in operation, through an adequate protection system;
- ensuring an operating regime without overshoots, using an multivariable control that can reduce the effect of the interactions;
- answer to specific quality objectives of the process, which suppose ensuring a conversion efficiency in the reactor (in riser) and a good combustion in the regenerator;
- answer to specific economic objectives, represented by maximizing of the yield gasoline in condition of the research octane number imposed.



a)

Fig. 1. The industrial fluid catalytic cracking.

The previous recommendations have constituted substantial reasons to develop the new control structures with increased performances.

In this context, the objective of this paper is to design a new control structure for the catalytic cracking process, using design and development techniques that are specific to chemical processes, respectively plantwide control.

Nomenclature

a	catalyst/feedstock contact ratio
H_{reg}	catalyst level in reactor
Q_{air}	air flow
Q_{cat1}	catalyst regenerate flow
Q_{feed},	feedstock flow
T_{feed}	feedstock temperature
T_r	ouput riser temperature
T_r^i	optimal riser temperature riser
T_{reg}	regenerator temperature
T_{reg1}	regenerated catalyst temperature
T_{reg}^i	optimal regenerator temperature
Y_G	yield gasoline
ΔP_3	pressure drop between reactor and regenerator

2. Plantwide control - overview

The approach into a hierarchical manner of the control activities associated to a chemical plant is known in specialized literature as planwide control. Practically, this approach is a design method for control system based on structural decisions and consists in four major steps, as follows [1]:

A. Specify the hierarchical control system design objectives, implying:
  - a1. the plant production and control objective;
  - a2. identify process constraints that must be satisfied, including safety, environmental, and quality restrictions.

B. Top-down analysis which consists:
  - b1. identify the process variables, control degrees of freedom, control structure and options for decomposition;
  - b2. establish, in conceptual form, the overall control structure;

C. Develop a bottom – up design, which supposes:
  - c1. develop a strategy for a regulator control;
  - c2. examine the potential of applying advanced control strategies;
  - c3. evaluate the economic benefits of real-time optimization;

D. Validate the proposed control structure

These step are based on the combined top-down, and bottom –up approaches of [1] and [2] and the hierarchical organization.

The plantwide control strategy has been studies by different chemical process complex like: HDA process [3], ethyl benzene process [4], VCM plant [5], Tennesse Eastman [6], reactor separator recycle system [7], acetylene hydrogenation process [8]. All these studies have confirmed improved of the performances economic for each plant.

3. Application of plantwide control strategy to the catalytic cracking process

The hierarchical control structure obtained by author after application of the plantwide strategy is presented in figure 2. The control structure contains three levels: the conventional control level; the advanced control level and the optimal control level.

Step A. The objectives of the control system designed specific to catalytic cracking process were presented in the introduction part of the paper. The constraints of the process are presented in table 1.

Table 1. The constraint of the process

Variables	Significance	Constraints type	Constraints	The limit
T_r	Riser output temperature	technological	$T_r < T_r^{max}$	570°C
T_{reg}	Regenerator temperature	technological	$T_{reg} < T_{reg}^{max}$	800°C
ΔP_3	Pressure drop between reactor and regenerator	safety	$\Delta P_3 < \Delta P_3^{max}$	3 bar
H_{reg}	Catalyst level in reactor	technological	$H_{reg}^{min} < H_{reg} < H_{reg}^{max}$	2 - 6 m

Step B. The second step supposes the selection of the process variables and the manipulated variables assigned for each hierarchical level.

- the third level – the specific variable is the yield gasoline (which is subjected to maximization) and manipulated variables identified are the riser outlet temperature - T_r^i and regenerator temperature $T_{reg}^{\ i}$. These variables are the setpoint for the second level. The perturbations of this level are the feed stock properties and catalyst properties.

- the second level – the specific variables are the riser outlet temperature - T_r^i and regenerator temperature -T_{reg}^i and the manipulated variables are the catalyst regenerate flow Q_{cat1} and the air flow Q_{air} that is needed for a combustion. These variables are determinate based on advanced control algorithm and are the setpoints for the first level.
- the first level – here are maintained the control variables and manipulates variables, that are specific to conventional control scheme associated to the catalytic cracking process,

This step is done by author crossing top-down the conceptual control scheme shown in figure1.

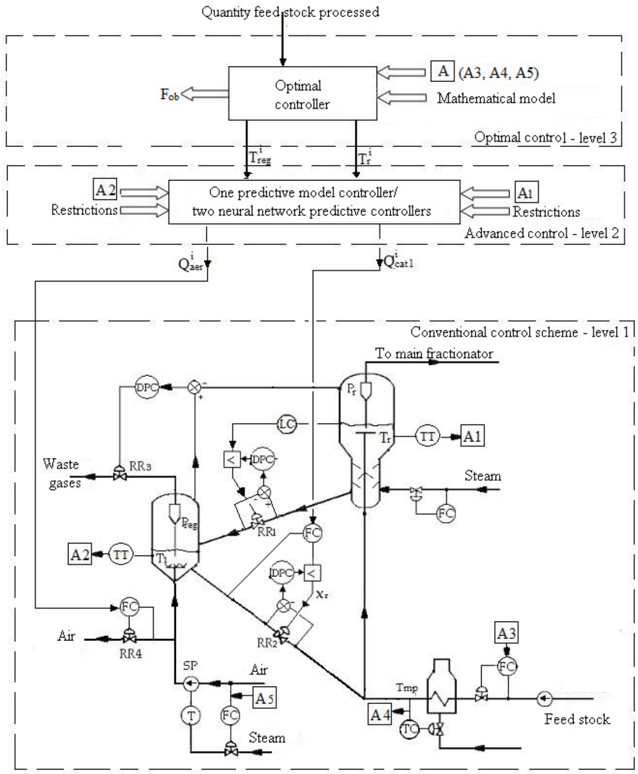


Fig. 2. The hierarchical control structure for the catalytic cracking process.

Step C. The third step of plantwide control strategy is to the select control loops associates to the catalytic cracking process. This step is done by crossing the down – top the conceptual control scheme.

- the first level associated to the conventional control of the process contains 10 monovariable control loops, two of these plays an important role to increasing the performance of the process. These are the riser outlet temperature control loop and difference temperature regenerator control loop, and were transferred to the second level.
- the second level is propose, implemented and testing two control strategy type: one centralized control strategy which used a model predictive controller and one decentralized control strategy which used two neural network model predictive controllers. The objectives of this level are riser outlet temperature control and temperature regenerator control. A conceptual representation of advanced control structure associated catalytic cracking process is shown in figure 3.

The input variable associates to the advanced controller are represented by disturbance variable (feedstock flow and temperature - Q_{feed}, T_{feed} and T_{reg1}- the regenerated catalyst temperature), the set point that are calculates at the high level (optimal riser temperature riser – T_r^i and optimal regenerator temperature - T_{reg}^i) and reaction variable process (riser temperature – T_r and regenerator temperature - T_{reg}). The manipulated variables are regenerated catalyst flow rate - Q_{cat1} and air flow in the regenerator - Q_{air}.

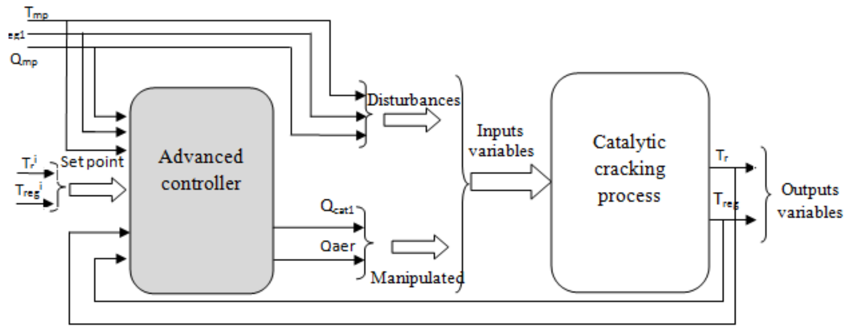


Fig. 3. The advanced control structure.

- the third level is represented by optimal controller. The goal of the optimal controller it to generate optimal setpoint of the predictive controller that is maximize the yield gasoline. The controller contains three components: an objective function, steady state process model and an optimal algorithm see fig 4a. The steady state process model developed by authors in paper [9] has been reduced the next form

$$[Y_G, T_r] = model\left(T_{reg}, a\right) \tag{1}$$

The objective function propose by authors is represented by yield of gasoline of the catalytic cracking of the process

$$F\left(T_{reg}, a\right) = Y_G \tag{2}$$

The process variable *a*, respectively catalyst/feedstock contact ratio, do not used that manipulate variable. Industrial practice recommends that manipulated variable the riser outlet temperature. In this condition, the author has proposed a correlation between the catalyst/feedstock contact ratio and the riser outlet temperature. The optimization module calculates the optimal value of the catalyst/feedstock contact ratio and after this operation the controller algorithm determines the optimal riser outlet temperature using the steady state process model.

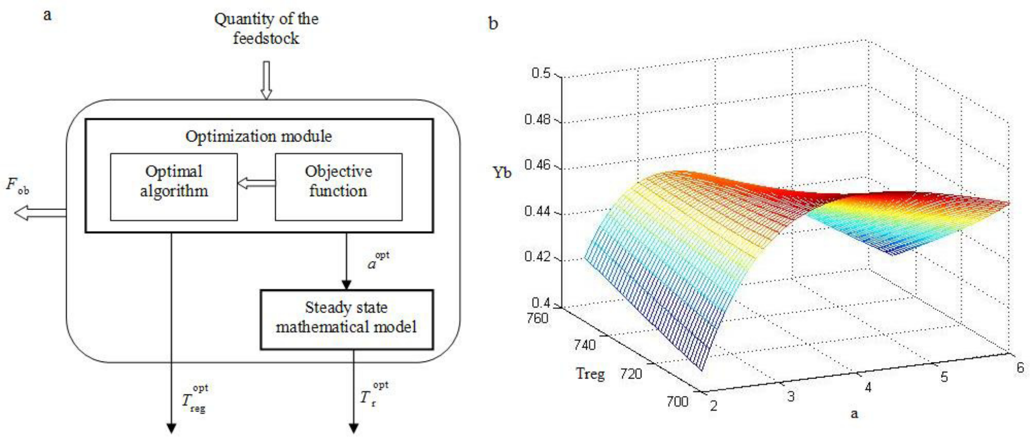


Fig. 4. a) the structure of the optimal controller; b) the objective function 3D graphic.

Step D. To validate the hierarchical control structure, the author has developed in Matlab a simulator, based on mathematical model presented in the paper [9]. The mathematical model was validated and adapted by author using industrial data collected from a Romanian catalytic cracking plant [10].

Performance investigation of the two control strategy associated to the second level consists in the evaluation of the effect of constraints and disturbances on manipulated and controlled variables. In the paper [11], the author demonstrated the viability of these two advanced control strategy.

For the three level, the author have implemented in Matlab a special program for dynamic simulator of the optimal controller. The 3D graphic of the function (2), see fig. 4b, has confirmed that function has an optimal region.

An estimation of the efficiency of the implementation of the hierarchical control structure can be performed by a comparison between industrial data and optimal data obtained, as shown in the figure 5. Based on this results, the yield gasoline is increasing with 2,5%.

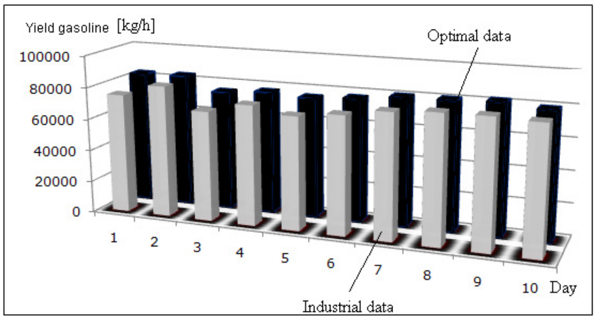


Fig. 5. The comparison between industrial data and optimal data of the yield gasoline.

4. Conclusion

The application of the plantwide control strategy to the catalytic cracking process led to a development of an hierarchical control structure with three levels. The plantwide control lead to choose the best controlled, manipulated, and measured variables in the plant, when are used advanced control techniques such as MPC, and how to select appropriate multiloop control structures with minimum interactions among.

In conclusion, this case study demonstrates that the implementation of the hierarchical control structure proposed by author can significantly affect process profitability.

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