

Robustness Improvement in Operating the Reactor – Regenerator Group for the Catalytic Cracking Unit Using Advanced Automation

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This paper presents the researches and the results obtained by the authors regarding the advanced automation of the reactor-regenerator group for the catalytic cracking unit. In this context an advanced control structure is proposed, which is implemented with feedback controllers based on the PID (Proportional – Integrator - Derivate) algorithm. The first part of the paper describes the reactor-regenerator group of the catalytic cracking unit and the associated conventional control structure. Afterwords, the paper presents the authors' proposed advanced control structure for the reactor-regenerator group. The last part highlights the results of the tests performed by the advanced control based on PID controllers. The simulation results show a robust functioning of the proposed control structure when the conditions for stationary and dynamic regime are met.

Keywords: fluid catalytic cracking, advanced control, PID algorithm, dynamic simulator

The fluid catalytic cracking unit (FCC) converts heavy distillates into gasoline and diesel using a catalyst in the fluidization bed. About 40% of the worldwide gasoline production comes from the FCC processes. Since a typical FCC unit can process a large amount of the feedstock into more valuable products, the overall economic benefits of a refinery could be considerably increased if proper control and optimization strategies are implemented. Unfortunately, in some refineries, old control systems are still found. The absence of advanced control systems from these plants has motivated researches in the field materialized through the elaboration of an advanced control system of the catalytic cracking process. Problems of the advanced control systems for the catalytic cracking process are presented in the literature [1-6, 8, 9], starting from which study, the authors propose an advanced control structure based on the PID algorithm.

The conventional control system

Process description. The unit in which the catalytic cracking process takes place contains four units: the interfusion node, riser, stripper and regenerator. In the mixing point, the fresh feed is atomized by superheated steam, then it is injected into the riser, and finally it is combined with the high temperature catalyst which comes from the regenerator. The catalyst together with the fresh feed vapours flow up into the riser, inside which the cracking reaction takes place. Inside the stripper, a separation between the catalyst and the reacted vapour products takes place. After separation, the catalyst with coke deposition becomes a spent catalyst. Then the spent catalyst is transported into the regenerator by the slope-pipe. The reacted vapour products are sent to the main fractionators, resulting in gasoline, residue, light and heavy diesel. In the regenerator, the coke deposited on the catalyst is burnt and the activity of the catalyst is recovered. The regenerated catalyst is then transported back to the mixing point through the regenerated-slope-pipe. After that,

the regenerated catalyst flows into the riser by rising steam and is then re-used in the riser.

Conventional control system. The conventional control structure, as depicted in figure 1, contains the next mono-variable feedback control systems [8]: the riser temperature control system (SRA-3), the catalyst level control system in stripper (SRA-1), two control systems associated to pressure drop on the valves RR1 and RR2, (SRA-2, respectively SRA-4), the fresh feed temperature control system (SRA-8), the fresh feed flow control system (SRA-9), the control system of the temperature difference between the upper and the lower part of the regenerator (fig. 1 as SRA-6), the control system of the pressure drop $\Delta P = P_1 - P_2$ between reactor and regenerator (in the fig. 1 as SRA-5). The control function and the corresponding manipulated variable of each control system are detailed in the papers [8, 12].

This conventional control structure ensures a stable steady state of the process, but it cannot reject variable interactions, namely the interactions between the control

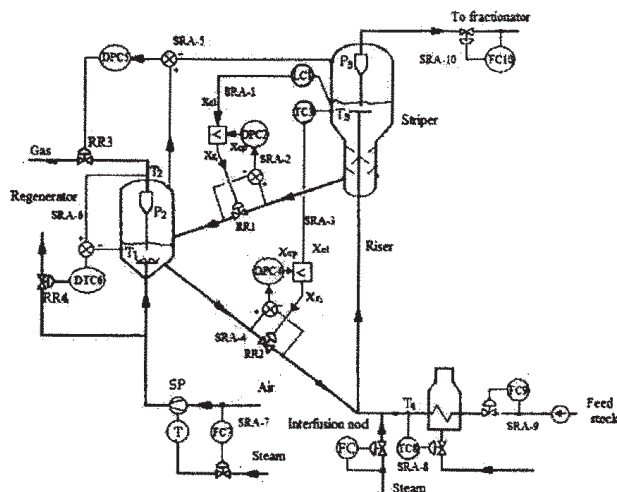


Fig. 1. The conventional control structure for the catalytic cracking process

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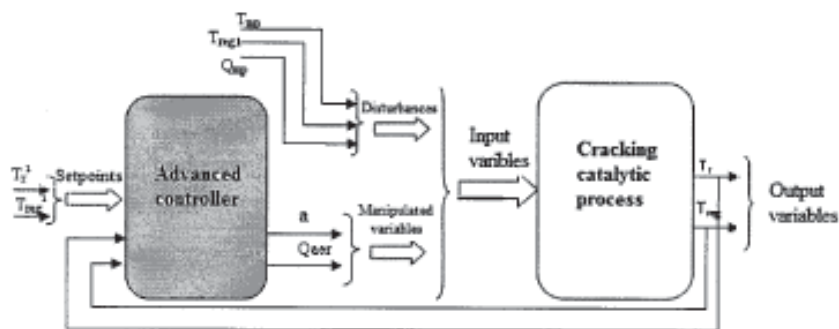


Fig. 2. The proposed advanced control system for the reactor – regenerator group of the catalytic cracking unit

loops. These interactions influence the process performance, including the economic efficiency as well.

The proposed advanced control system for the reactor – regenerator group

Of all the mono-variable conventional control systems, two directly influence the quality and efficiency objectives of the process. These are the output riser temperature control system (SRA-3) and the control system for temperature difference in the regenerator (SRA-6). In connection to the two control systems, this paper proposes their replacement with an advanced control system as depicted in figure 2.

The proposed control system contains a multivariable controller whose commands are the contact ratio - a and the air flow - Q_{air} . The set points are the riser temperature T_r^i and the regenerator temperature T_{reg}^i . The control system is feedback type, which involves informing the multivariable controller about the process output variables (T_r and T_{reg}).

The implementation of the PID control structure

Nowadays, the PID controllers are used in about 80% of the chemical plants automation. This is justified by the performances and the robustness of these controllers. In figure 3, the command $u(t)$ summarizes three components,

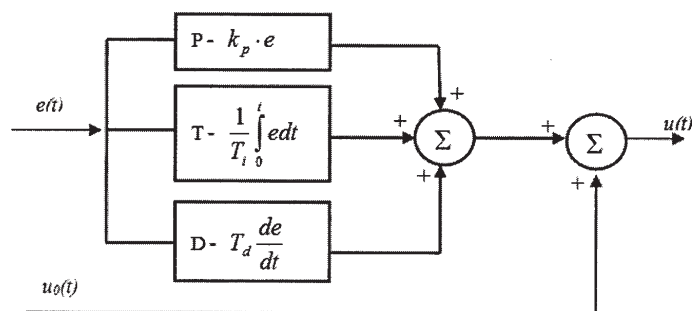


Fig. 3. The structure of the PID controller

respectively: proportional, integrative, derivative, which generate outcomes as detailed in the papers [4,8]. The dynamic command of a PID controller is calculated as below:

$$u(t) = u_0(t) + k_p(e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{de}{dt}), \quad (1)$$

where:

- u is the current command;
- u_0 - the initial command,
- k_p - the gain;
- T_i - the integration constant;
- T_d - the derivation constant.

The constants k_p, T_i, T_d known as tuning parameters, directly influence the performances of the control loop. The identification of the optimal values of these constants is obtained by the tuning controller, which may be realized using analytical or empirical methods [4, 8].

The implementation of the structure from figure 2 is realized by two PID controllers, respectively: PID1 associated with the output riser temperature control system, where the controlled variable is the contact ratio a , and PID2 associated with the control system of the temperature difference from the regenerator, where the controlled variable is the air flow Q_{air} .

In order to analyze the performances of the proposed structure, the process is considered to be represented by the mathematical model developed in papers [12, 13]. This model has been validated for a middle operating point of an industrial plant characterized by the parameter values presented in table 1.

According to figure 4, which depicts the implementation structure for one of the controllers, two distinctive stages appear: the model linearization and controller tuning respectively. These stages are performed off-line, employing the PID tuning package from MATLAB - SIMULINK® environment, the tuning method being realized through an empirical method such as Ziegler- Nichols.

Process parameters	Variable	Value	Units
Feed stock temperature	T_{mp}	195	$^{\circ}\text{C}$
Rgenerated catalyst temperature	T_{reg1}	709	$^{\circ}\text{C}$
Fresh feed flow	Q_{mp}	161750	kg/h
Contact ratio	a	4.59	-
Mixture point temperature	T_{nod}	573	$^{\circ}\text{C}$
Output riser temperature	T_r	528	$^{\circ}\text{C}$
Striper inside temperature	T_s	528	$^{\circ}\text{C}$
Coke masic fraction on catalyst in striper	C_{cocs2}	0.13	-
Regenerator temperature	T_{reg}	722	$^{\circ}\text{C}$
Coke masic fraction on regenerated catalyst	C_{cocs3}	0.77	-

Table 1
THE PROCESS PARAMETER
VALUES FOR A MIDDLE
OPERATING POINT

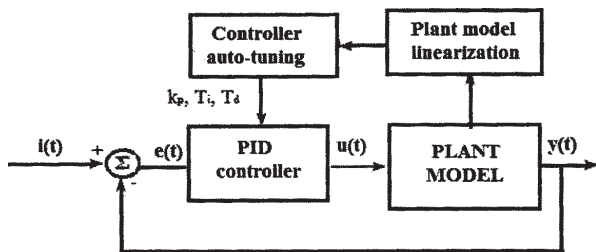


Fig. 4. The bloc diagram for PID tuning controller.

Table 2 contains the tuning parameter values for the PID1 and PID2 controller. These values were obtained based on the process parameter values for a middle operating point from table 1.

Table 2
TUNING PARAMETER VALUES FOR
PID CONTROLLERS

PID controller	K_p	T_i	T_d
PID1	0.241	0.789	0
PID2	1.31	0.48	0

The testing of the proposed structure

In order to test the performances of the PID advanced control for reactor-regenerator group, the simulator depicted in figure 5 was developed in MATLAB - SIMULINK® environment, simulator which allows the testing of the proposed control structure by adjusting the setpoints and disturbances.

The first set of tests consisted in evaluating the dynamic response of the automatic system proposed, at step variation of the setpoints (the output riser temperature T_r^i , the regenerator temperature T_{reg}^i). Figures 6 and 7 show the dynamic responses of the parameters T_r and T_{reg} together with the dynamic evolutions of the commands (a- contact ratio respectively Q_{air} - air flow) at modifying the setpoints (de la 529 la 539°C, de la 709 la 719 °C).

From the graphic representations corresponding to the first test, it can be observed that the two control systems are functional in the sense that they can bring the controlled variables to the setpoints value without error in steady state and insignificant overshoot (below 1°C). Duration of the transient regimes is under 20 s, being lower than in the case of the conventional structure.

The second set of tests was represented by the assessment of the dynamic response of the controlled

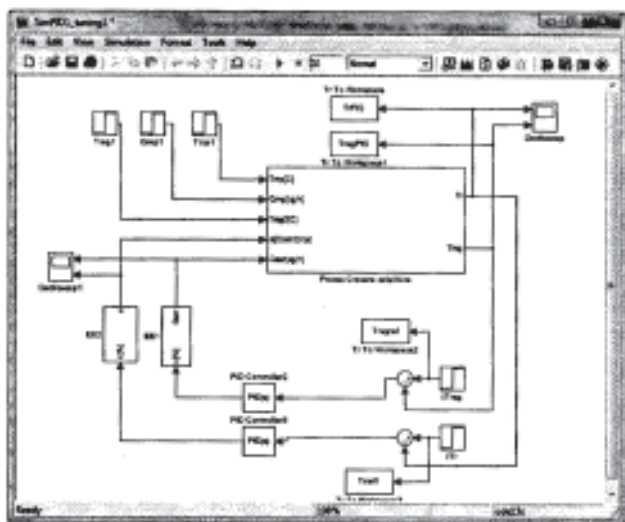


Fig. 5. The simulator screen for the proposed control structure

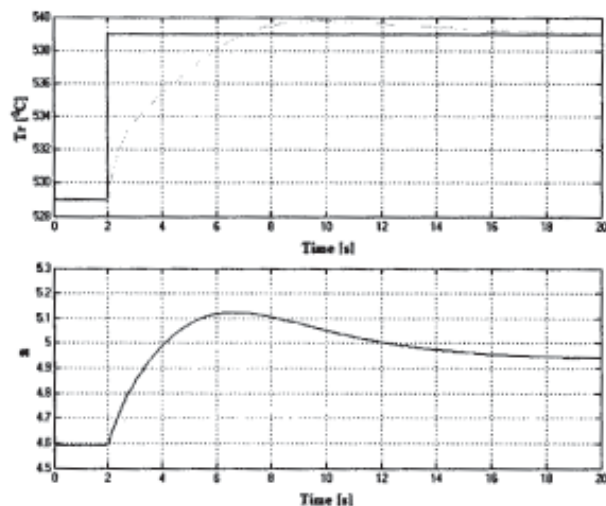


Fig. 6. The dynamic evolution of the riser outlet temperature and contacting ratio when the controller setpoint - T_r increases from 529 to 539 °C.

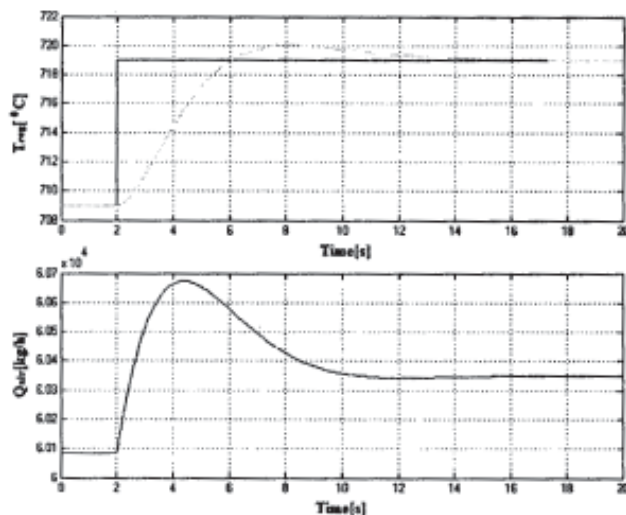


Fig. 7. The dynamic evolution of the regenerator temperature and air flow rate when controller set point - T_{reg} increases from 709 to 719 °C

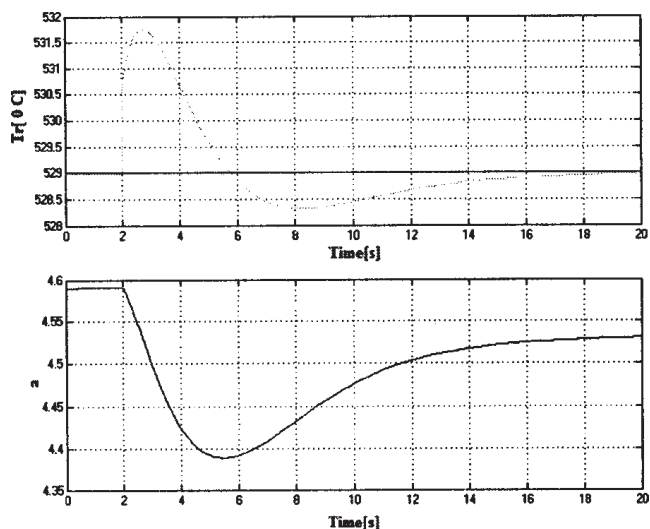


Fig. 8. The dynamic evolution of the riser outlet temperature and contact ratio when the feedstock temperature increases from 195 to 205 °C.

variables (the output riser temperature the regenerator temperature) at the modification of several various disturbances. Figures 8 and 9 present the dynamic response of the output riser temperature T_r , the regenerator

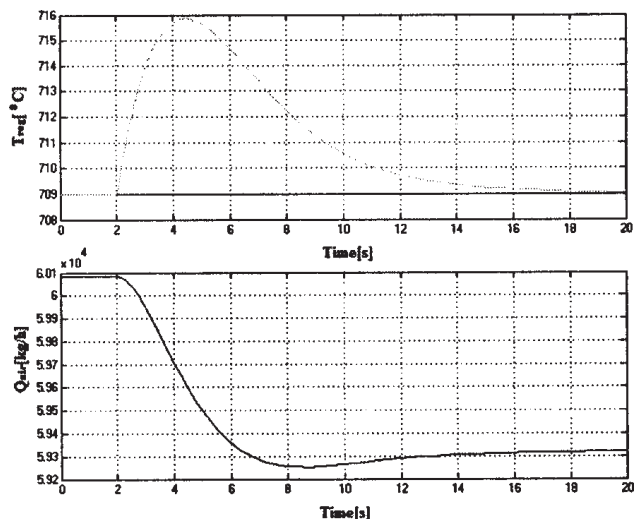


Fig. 9. The dynamic evolution in time of the regenerated catalysts temperature and air flow when the feedstock temperature increases from 195 to 205°C

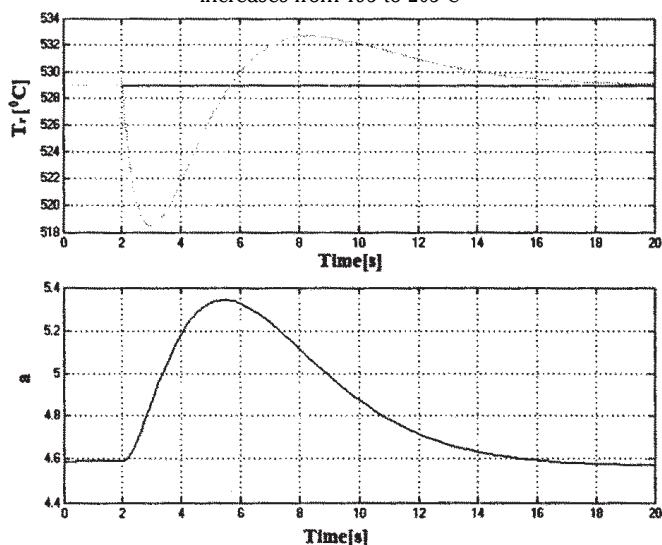


Fig. 10. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the feedstock flow increases from 161750 kg/h la 171750 kg/h.

temperature T_{reg} and the commands (α - contact ratio respectively Q_{air} - flow air) at the step variation of the disturbance T_{mp} from 195 to 215 °C.

Examining the graphic representations in figures 8 and 9 it can be observed that the control system eliminates the errors caused by disturbances, the duration of the transient regime being of about 15s. One can practically observe the lack of oscillations, which confirms the robustness of the solution.

In figures 10 and 11, the dynamic evolutions of the control variables are shown, at the modification of the perturbation Q_{mp} from 161750 kg/h to 171750 kg/h. In this case, the durations of the transient regime can be observed in conformity with the inertia of the process and, and as in the case of the previous one, it can be observed that there are practically no oscillations.

Conclusions

The current paper presents in a synthetic manner the authors research results regarding the development and the implementation of the advanced control structures for the reactor-regenerator group within a catalytic cracking unit. The advanced structure, which supposes the use of the contact ratio and air flow rate, as manipulated variables in order to control the two essential parameters of the

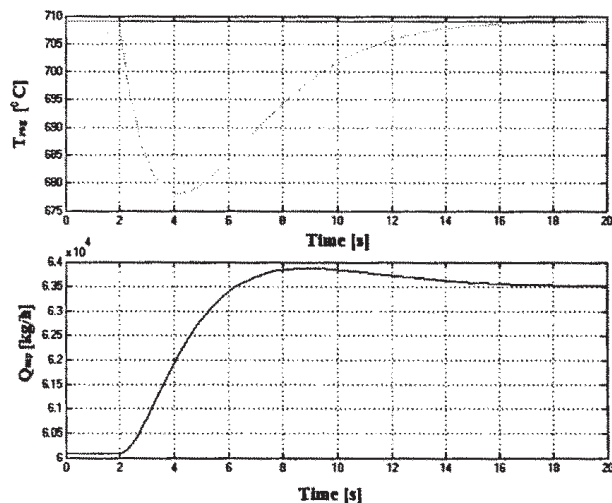


Fig. 11. The dynamic evolution in time of the regenerated catalysts temperature and air flow when the feedstock flow increases from 161750 kg/h la 171750kg/h.

catalytic cracking process, namely: the reactor temperature and the regenerator temperature.

In order to implement the control structure, a multivariable controller based on the PID algorithm was proposed. For the testing of the proposed control structure, a simulator developed in the MATLAB –SIMULINK® environment was elaborated. The results of the simulations, respectively the dynamic of the control output (the output riser temperature T_r and the regenerator temperature T_{reg}) at step variation of the setpoint and disturbances highlight the superior performances in comparison with the conventional control structure from the point of view of control quality and robustness. These performances are notable, taking into account the fact that the reactor – regenerator group is the heart of the catalytic cracking unit and its proper functioning from the point of view of its quality and efficiency influences the performances of the entire catalytic cracking plant.

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