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Comparison of PI and MPC for Control of Catalytic Cracking Process

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Abstract

This study compares PI and MPC control via computer simulation for a catalytic cracking process. The conventional control of catalytic cracking process is based on PI algorithm, and ensures a stabile operating regime but from economic point of view is inefficient. The implementation of model predictive control (MPC) controller led to optimize the plant operation. The topic approached in the paper are: process describe, the conventional control structure base PI control, the overview of the model based predictive control concept and the development of the predictive controller for the catalytic cracking process. In the last part will be outline the performance obtained using the model predictive controller for catalytic cracking process.

Key words: *control, model predictive control, catalytic cracking process*

Introduction

In many industrial process, the conventional control structure is based on PID controllers, with it is able to maintain the process variable about the given setpoint values. In case of the catalytic cracking process, the conventional control structure ensure stabile operating regime but it cannot eliminate the strong interaction between the variables of the process respectively between control loops. In consequence, the process efficiency and optimality can be improved adopting advanced control techniques – model predictive control. The literature is relatively rich in modeling and simulation studies of the catalytic cracking process [6]. A much more reduced category of works deal with aspects of the advanced process control of the FCCU, the proposed control algorithms being tested by mathematical model of the process [1, 4].

In this paper is showed that the MPC controller has better performance compared to classical PI control scheme and allows taking in account all constraints.

Process Description

The fluid catalytic cracking unit (FCC) is an important process in oil refineries and it used to convert the petroleum crude oil to more valuable gasoline, gases and other products in the present of the catalyst. The FCCU is a complex process and consist three major components the riser, the reactor and the regenerator. In the riser takes place cracking reaction, which is controlled by the catalyst. After that, the oil vapors' obtain and the catalyst pass into reactor where the catalyst is separated by means of cyclones. The catalyst goes to the regenerator, where the coke formed on the catalyst during the cracking reaction is burning. The catalyst fluidized is move between the regenerator and reactor by means of pressure differential. The pre-heated oil and hot catalyst from regenerator enter in riser. A typically scheme of FCC is show in figure 1 [5].

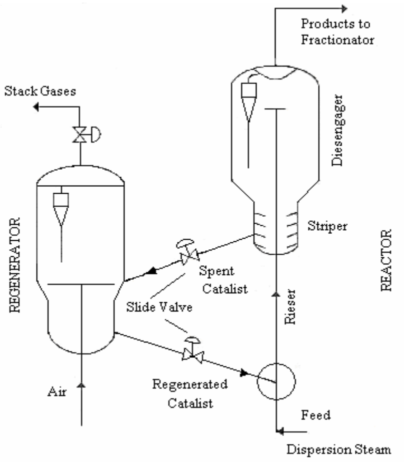

Fig. 1. Scheme of FCC.

PI Control of the FCC

The conventional control structure of the FCC is based on 10 monovariables control loops, which ensure a stable operating regime [4]. Form this 10 monovariables control loops, two play an important role to increasing the performance of the process. These are the riser outlet temperature control loop and difference temperature regenerator control loop. In practice, the riser outlet temperature is used to control the conversion and the regenerator temperature is used to control the combustion.

A conceptual representation of control structure base on PI associated to the catalytic cracking process is presented in figure 2. The input variables of the control structure base on PI are:

- measured disturbances of the process (the feedstock temperature – T_{mp}, regenerated catalyst temperature - $\mathrm{T_{reg1}}$, feedstock flow - Q_{mp});
- the setpoint of the controller (riser outlet temperature - T_r^i and regenerator temperature - T_{reg}^i);
- the feedback variables of the process (riser outlet temperature – T_r and regenerator temperature - T_{reg}).

Regarding the manipulated variables of the controller, these are the regenerated catalyst flow – Q_{cat1} and air flow in the regenerator – Q_{air}..

To analyze the performance of these two control loops based on PI algorithm, the author has used the simulator develop in Simulink. The mathematical model used to develop the simulator is presented by author in the paper [5].

Investigation performance of the control structures base on PI consists in the modification of the setpoint (riser outlet temperature T_r, the regenerator temperature T_{reg}) and the disturbances which appears in the process (the feedstock flow Q_{mp}, the feedstock temperature, and the regenerated catalyst temperature T_{reg1}). For PI controller are considered the following default simulation parameters:

- for reactor controller: kp=0.9, Ti=4min;
- for regenerator controller: kp=0.5, Ti=5min.

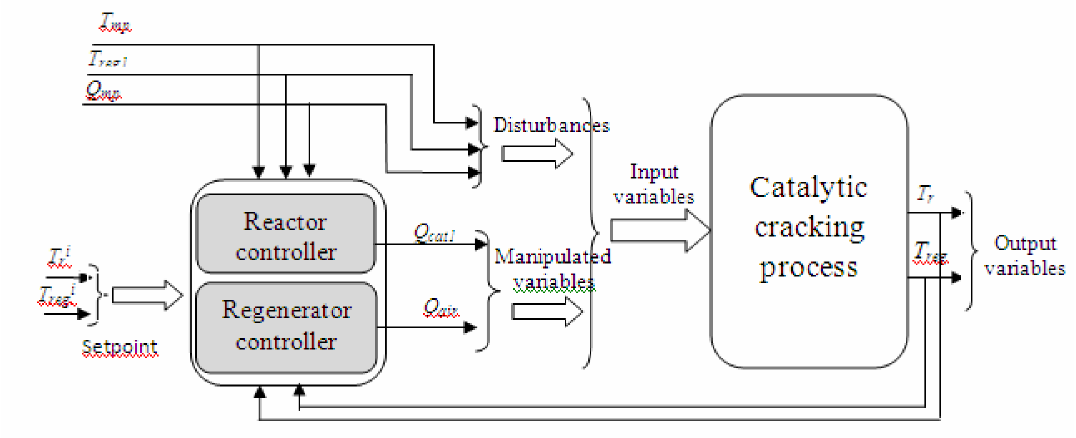

Fig. 2. The control structure base on PI.

To determine the performance of the control structure base on PI, the author runs two types of tests.

The A test consist in modifying the references of the controller (riser outlet temperature T_r, the regenerator temperature T_{reg1}) in step variations. In figures 3 and 4 are presented the dynamic evolution of this variable, together with the manipulated variables associate (Q_{cat1} and Q_{air}).

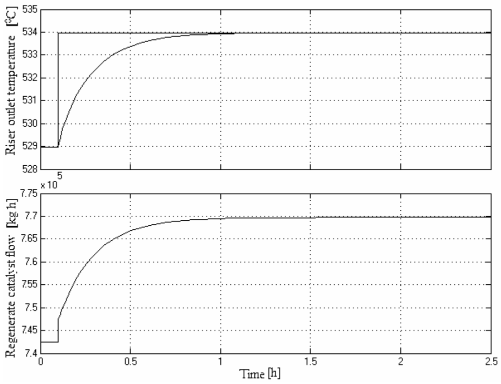

Fig. 3. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the controller setpoint Tr increases from 529 ^{0}C to 534^{0}C.

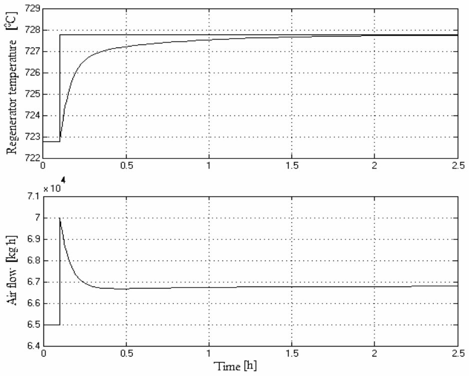

Fig. 4. The dynamic evolution of the regenerator temperature and air flow rate when controller set point - T_{reg1} increases from 722.97^{0}C to 732.97 ^{0}C.

The B test consists in modifying the disturbance of the system. In figure 5 and 6 are presented the dynamic evolution of the riser outlet temperature - T_s, the regenerated catalyst temperature T_{reg1} and the manipulated variable associated when one of the disturbances (here feedstock temperature) is change.

MPC Control of the FCC

Model based predictive control is known to be a very powerful control strategy for variety of chemical process [2]. The predictive algorithm contains two components: *a predictor* and *an optimizer*.

The predictor uses an explicit model of the process for predicting the way that the process output will evolve in the future, over a specified time horizon. The explicit model can be as linear/nonlinear input-output relations.

The optimizer uses the predictions to calculate the control variable value, that is obtain by minimizes an objective function, without violating the inputs and outputs constraints. The objective function is done by minimizing the sum differences between the predicted process output values $\hat{y}_{k+i}$ and setpoint values r_{k+I} , starting from the current step k, for p step in the future, and square rate of control variable variations.

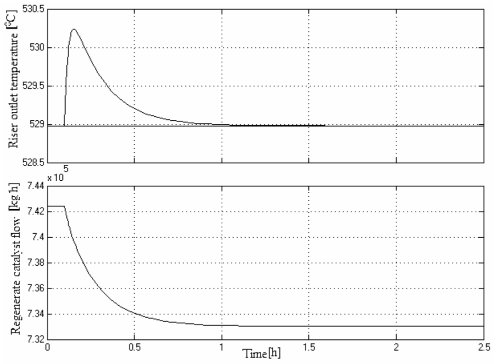

Fig. 5. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the feed stock temperature increases from 195 ^{0}C to 215 ^{0}C.

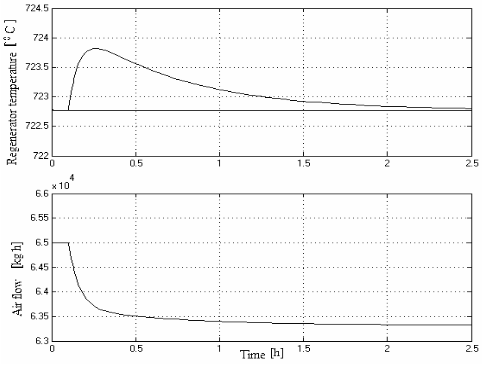

Fig. 6. The dynamic evolution of the regenerated catalysts temperature and air flow when the feedstock increases from the 195^{0}C to 215 ^{0}C.

A conceptual representation of the predictive control structure associated to the catalytic cracking process is presented in figure 7. [5]

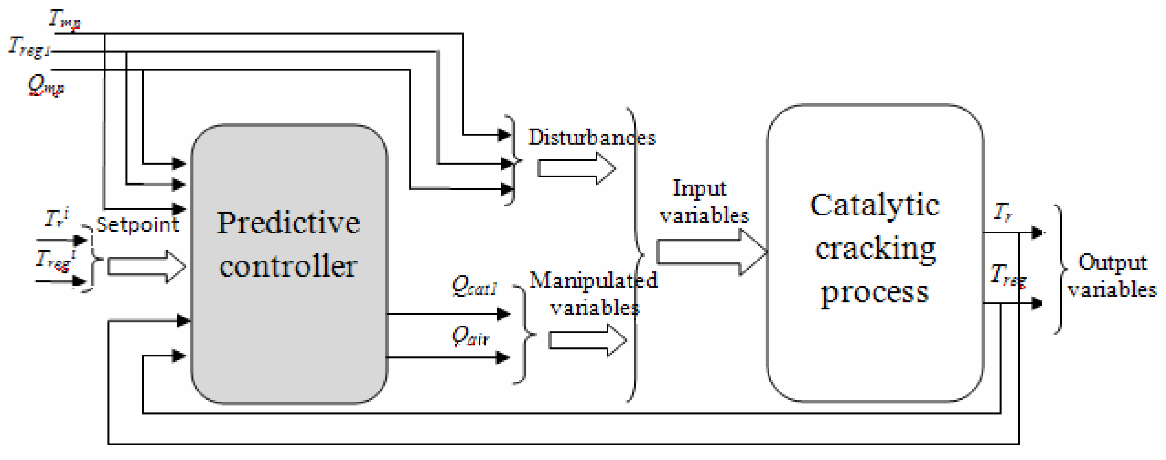

Fig. 7. The predictive control structure of the catalytic cracking process.

Develop an MPC controller Matlab(Simulink) for the catalytic cracking process suppose the linierized the model of process, for to obtain the model simplified of the process. The model simplified is obtained used the process identification test presented in paper [5].

The investigation performance of the predictive control system consisted in modifying the setpoint (outlet riser temperature T_r, the regenerator temperature T_{reg}) and the disturbances which appears in the process (the feedstock flow Q_{feed}, the feedstock temperature, and the regenerated catalyst temperature T_{reg1}).

The A test, which consist in modifying the references of the controller. In figures 8 and 9 are presented the dynamic evolution of this variables, together with the manipulated variables associate (Q_{cat1} and Q_{air}). As can be seen from the above trends, the multivariable controller system successes fully bring the output values to the setpoint values, without state steady error and the time of dynamic regime is smaller.

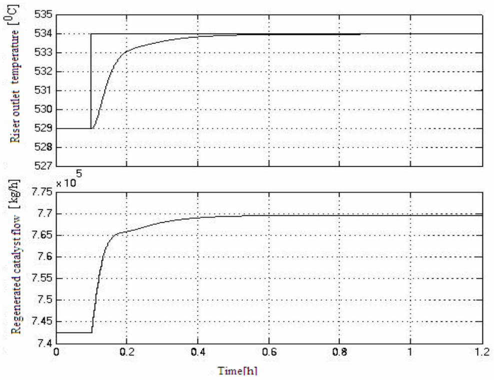

Fig. 8. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the controller setpoint - T_r increases from 529 ^{0}C to 534^{0}C.

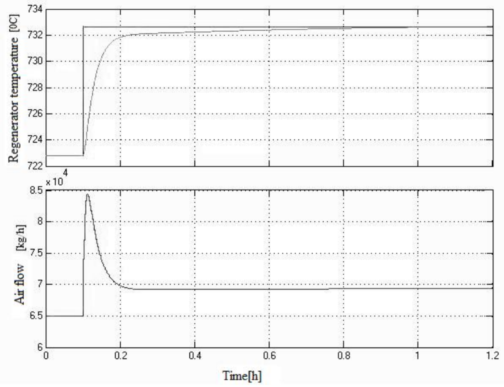

Fig. 9. The dynamic evolution of the regenerator temperature and air flow rate when controller set point - T_{reg1} increases from 722.97^{0}C to 732.97 ^{0}C.

The B test consists in to modifying the disturbance of the system. In figure 10 and 11 are presented the dynamic evolution of the riser outlet temperature - T_s, the regenerated catalyst temperature T_{reg1} and the manipulated variable associated when one of the disturbances (here feedstock temperature) is change.

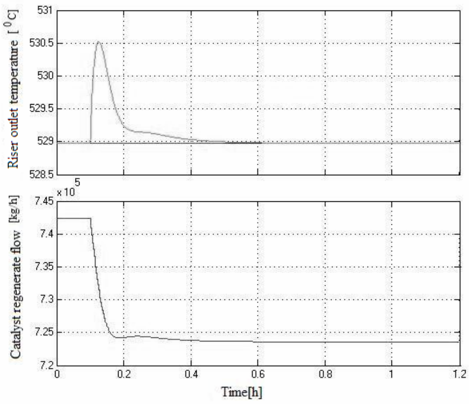

Fig. 10. The dynamic evolution of the riser outlet temperature and regenerated catalyst flow when the feed stock temperature increases from 195^{0}C to 215 ^{0}C.

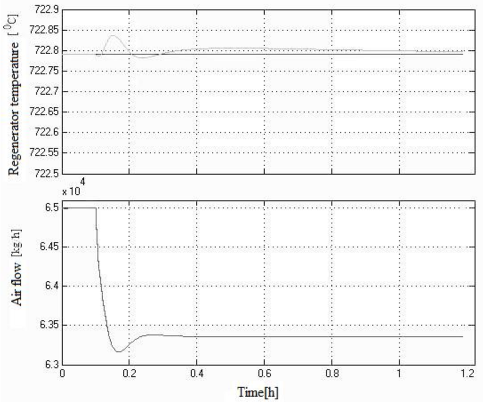

Fig. 11. The evolution in time of the regenerated catalysts temperature and air flow when the feedstock increases from the 195^{0}C to 215 ^{0}C.

From results associated to the B test can be observed that the control system eliminates the effect of the distributions which appear in the process and the time of the dynamic regime is smaller.

Conclusion

In this paper is presented a compares between PI control and MPC control structure applied to catalytic cracking process. The advantages for using MPC control structure are:

- the MPC control structure successes fully bring the output values to the set point values, without state steady error and the time of dynamic regime is more smaller;
- the MPC control structure successes eliminates the effect of the distributions which appear in the process and the time of the dynamic regime is more smaller.

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Comparație între reglarea PI şi MPC pentru procesul de cracare catalitică

Rezumat

Acest studiu compara algoritmul PI şi MPC prin simularea pe calculator pentru un proces de cracare catalitică. Reglarea convențional a procesului de cracare catalitică se bazează pe algoritmul de PI , acesta asigurând un regim de operare stabil, dar din punct de vedere economic este ineficient. Punerea în aplicare a reglări predictive bazate pe model ar duce la optimizarea funcționării instalației. In cadrul lucrări sunt abordate următoarele probleme: descrierea procesului de cracare catalitică, descrierea structuri de reglare convențională asociată procesului de cracare catalitică, privire de ansamblu asupra conceptului de reglare predictive bazata pe model. In ultima parte vor fi conturate performanțele obținute prin implementarea regulatorului predictiv procesului de cracare catalitică.