Efficient Operation of Reaction Group from a Catalytic Cracking Plant through Fuzzy Control

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The current paper presents the research results obtained by the authors regarding the automation of the reactor - regenerator group associated with the catalytic cracking process, using a control system based on fuzzy logic. The first part of the paper describes the control structure proposed for the reactor - regenerator group and the corresponding steps of the development of the fuzzy controller. The second part of the paper highlights the results of testing with the proposed control structure. The results of the simulation have shown comparable or even superior performance against to the specific use of conventional techniques.

Keywords: fluid catalytic cracking, fuzzy logical control, modelling and simulation

A significant way to increase the efficiency of a process and, therefore, that of catalytic cracking, also recommended by Shinskey [1], is by means of the advanced automation. Relevant in this regard are the predictive control based on model [2 - 5] and the internal model control [6]. In addition, these also are control systems based on artificial intelligence techniques such as neural networks [7, 8], genetic algorithms [9], fuzzy logic [10- 12].

Among these techniques, the fuzzy logic control knows no significant implementations for the catalytic cracking process. The highlighted arguments have motivated the authors of this article to investigate the advanced control based on the fuzzy technique of the catalytic cracking process.

Structure of the control system based on fuzzy logic

The starting point in developing the control structure based on fuzzy logic was represented by the conventional control structure presented by the authors in [13]. This conventional control structure includes nine monovariable feedback control systems. Two of them, namely the automatic control systems of the temperatures in the riser and the striper have a direct impact on the efficiency of the catalytic cracking process. Considering this, the control structures based on fuzzy logic, illustrated in figure 1, is proposed in order to control these two temperatures. The proposed structure contains a multivariable fuzzy controller with the references represented by riser temperature - T_r^i and regenerator temperature- T_{reg}^i, these commands being constituted from the contact ratio- a and the air flow rate - Q_{aer}.

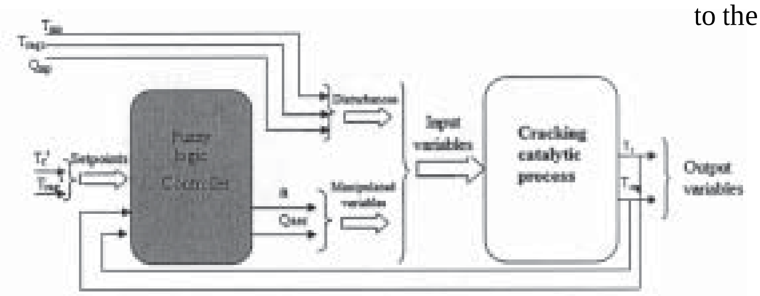

Fig. 1. The control fuzzy system for the catalytic cracking process

As for as the significant disturbances that influence the proposed control system, these include: feedstock temperature - T_{mp}, regenerated catalyst temperature - T_{reg1}, feedstock flow rate – Q_{mp}.

Developing the fuzzy logic controller

Structure of the fuzzy controller

Fuzzy sets have been introduced by Lofti Zadeh in 1965 [14], such sets being characterized by a membership function that assigns to each element a membership degree in the range [0, 1]. The fuzzy control systems are based on qualitative estimates of the specific measures and on the correlations between these, linguistically expressed through a set of rules. For the synthesis of the fuzzy controller it is not necessary to know the process model, but knowledge and experience in modelling it are important.

According to Passino and Janten [15, 16] a fuzzy controller contains the following four basic elements, illustrated in figure 2:

-a fuzzification module, which converts the crisp input values into fuzzy information (linguistic variables, linguistic terms, membership function);

-a knowledge base, that contains a set of rules of the operation experience of the process;

-an inference module, which establishes the rules that are applicable at a give time based on the membership degree and which determines the fuzzy values of the command controller;

-a defuzzification module, which has the role of converting the information received from the inference mechanism into a crisp value, which will be transmitted to the process through the actuator.

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Fig. 3. The membership function for input variable

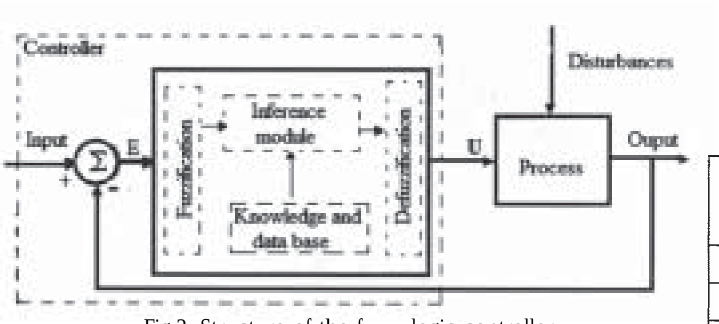

Fig.2. Structure of the fuzzy logic controller.

Development of the controller

The first step in the development of the fuzzy controller is the choice of the input and output variables, as well as their variation domain. The input variables associated with the controller are riser temperature – T_r and regenerator temperature - T_{reg} together with the setpoint Tr^i and T_{reg}^i and the output variables are catalyst/ feedstock flow ratio - *a* and air flow rate in the regenerator - Q_{aer}. In the fuzzy system domain, the input and output variables of the controller are called linguistic variables.

The second step consists in defining fuzzy sets (linguistic values) associated with linguistic variables and membership functions. Table 1 shows the possible linguistic values for the four linguistic variables of the developed fuzzy controller.

The next step in the synthesis of the fuzzy controller is represented by defining of the base rules. This is achieved through the logic correlation of the fuzzy sets of the output variables with those of the input variables. The correlation operation which makes it possible to switch from premises to conclusions represents an inference. Tables 2 and 3 contain the proposed support matrix for the inference formulation corresponding to the developed fuzzy controller.

Starting from the matrices in tables 2 and 3 are built inferences in the form of 25 logical implications as ***if*** *[(Treg is ...)* ***and*** *(Tr is ...)]****then*** *[(Qaer is ...)* ***and*** *(a is ...)].*

Implementation of the fuzzy controller

The implementation of the proposed fuzzy controller was carried out using the facilities of the Fuzzy Logic Toolbox ™ package (*FLT)* within the MATLAB® environment. In the first stage were generated the triangular type membership functions for all variables involved. For this purpose the Membership Function Editor of *FLT* was used. Figures 3 and 4 show the membership functions for inputs T_{reg} and T_r and figures 5 and 6 highlight the same functions for the outputs *Qaer* and *a*. In the second stage the 25 rules synthesized in the support matrices in tables 2 and 3 were

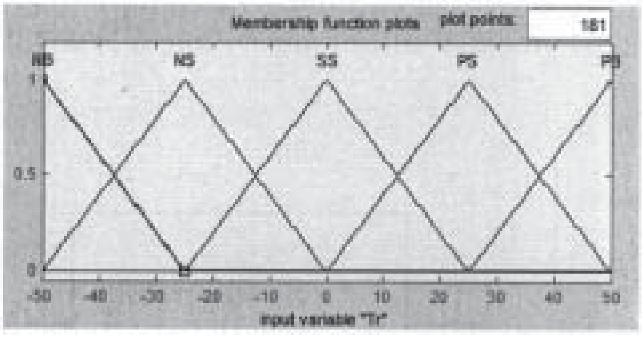

Fig. 3. The membership function for input variable T_r

Table 1

LINGUISTIC VALUES PROPOSED FOR THE VARIABLES OF THE FUZZY CONTROLLER

The linguistic values proposed for the linguistic input variables T_r şi T_{reg}	The linguistic values proposed for the linguistic output variables a şi Q_{aer}
NB - negative big	**NB**- negative big
NS – negative small	**NS** – negative small
SS - steady state	**SS** - steady state
PS - positive small	**PS** - positive small
PB – positive big	**PB** – positive big

Table 2

THE SUPPORT MATRIX FOR THE SPECIFIC INFERENCE OF THE LINGUISTIC VARIABLE Q_{aer} .

Linguistic values for the variable Q_{aer}		Linguistic values for the variable T_r				
		NB	NS	SS	PS	PB
Linguistic values for the variable T_{reg}	NB	**NB**	**NB**	**SS**	**PB**	**PB**
	NS	**NB**	**NB**	**SS**	**PS**	**PS**
	SS	**NS**	**NS**	**SS**	**PS**	**PS**
	PS	**NS**	**NS**	**SS**	**PB**	**PB**
	PB	**NS**	**NS**	**SS**	**PB**	**PB**

Table 3

THE SUPPORT MATRIX FOR THE SPECIFIC INFERENCE OF THE LINGUISTIC VARIABLE *a*

Linguistic values for the variable *a*		Linguistic values for the variable T_r				
		NB	NS	SS	PS	PB
Linguistic values for the variable T_{reg}	NB	**NB**	**NS**	**PB**	**PB**	**PB**
	NS	**NB**	**NS**	**PB**	**PB**	**PB**
	SS	**NB**	**NB**	**SS**	**PS**	**PB**
	PS	**NB**	**NB**	**NB**	**NS**	**NB**
	PB	**NB**	**NB**	**NB**	**NS**	**NB**

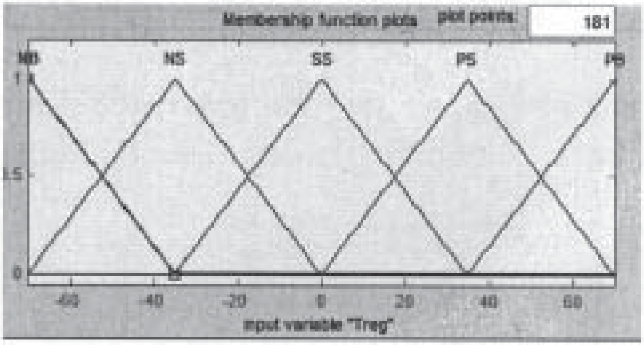

Fig. 4. The membership function for input variable T_{reg}

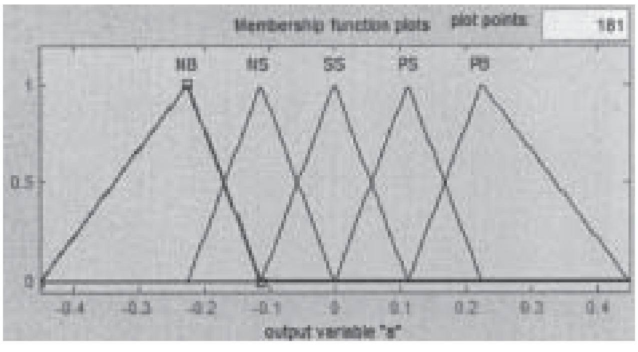

Fig. 5. The membership function for output variable *a*.

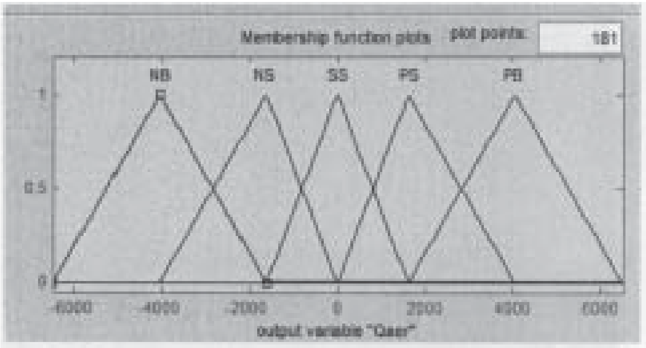

Fig. 6. The membership function for output variable Q_{aer}

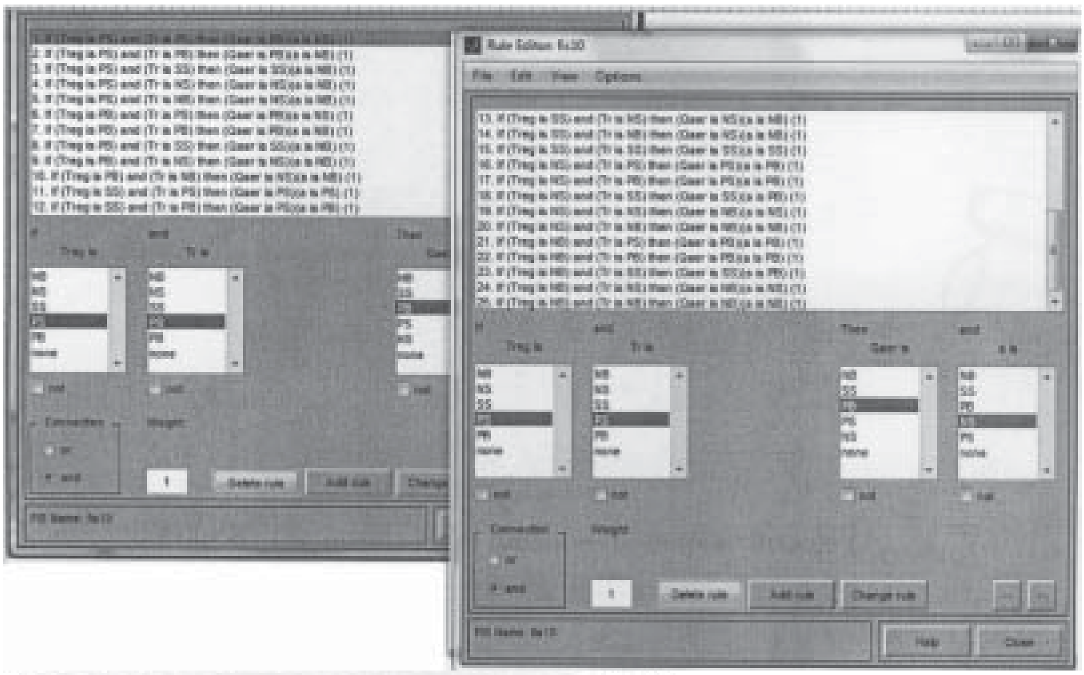

Fig. 7. The set of rules associated with the implemented fuzzy controller.

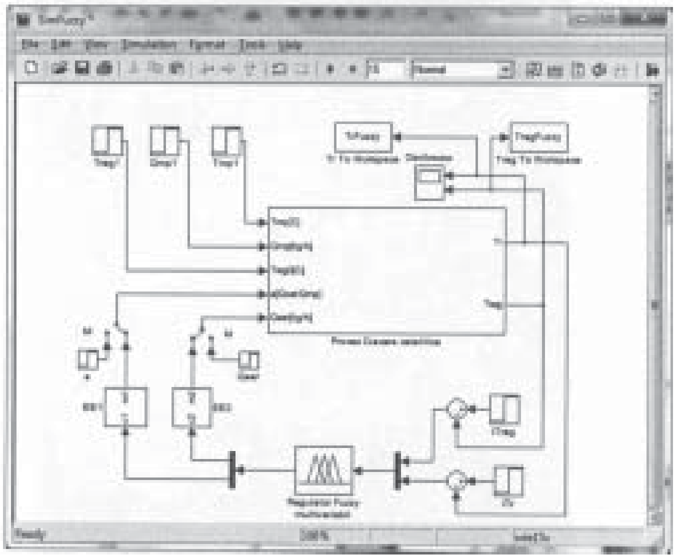

Fig. 8. The Simulink® program for testing the developed fuzzy control structure.

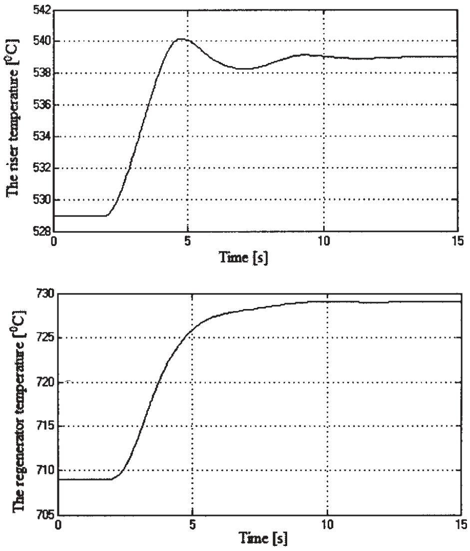

Fig. 9. The dynamic evolution of the riser outlet temperature and regenerator temperature when the controller setpoints – T_{reg} increases from 709 °C to 729 °C respectively T_r increases from 529 °C to 539°C.

edited using the Rule Editor of *FLT*. These rules are outlined in the screens (Rule Viewer) in figure 7.

The fuzzy controller, generated by the *FTL* Toolbox, was connected to the reactor-regenerator simulator , developed by the first author of the current paper and described in reference [3]. Figure 8 presents the implementation in Simulink® of the control structure in figure 1, which includes the process simulator and the fuzzy controller[12].

Performances of the proposed control structure

The dynamic and steady state performances of the control system based on the developed fuzzy control were evaluated based on the simulation results, executed on the simulator presented in figure 8. The simulations have are supposed the determination of the dynamic evolution of the proposed control system at the application of step variations of the setpoint (first set of tests) and disturbances (the second set of tests).

Figure 9 presents an example which includes the dynamic responses of the control parameters T_r and T_{reg} at the application of step changes from 10 ⁰C for setpoint (T_r^i from 529 ⁰C to 539⁰C, and T_{reg}^i from 709 ⁰C to 719 ⁰C).

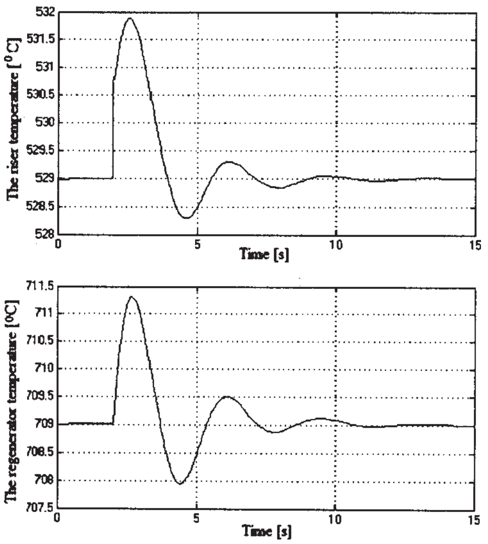

Fig. 10. The dynamic evolution of the riser outlet temperature and temperature regenerator when the feedstock temperature increases from 195 ^{0}C to 215 ^{0}C .

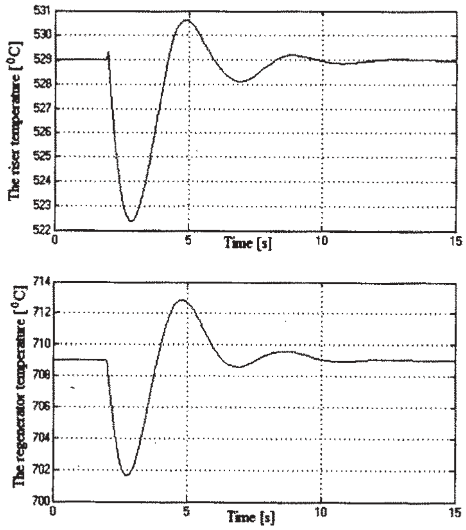

Fig. 11. The dynamic evolution of the riser outlet temperature and temperature regenerator when the feedstock flow increases from 161750 kg/h to 166750 kg/h.

Figures 10 and 11 indicate the results of simulations that highlight the dynamic evolution of the riser and regenerator temperatures (T_r and T_{reg}) at 20 ^{0}C step variations of the fresh feed temperature (from 195 ^{0}C to 215 ^{0}C)and by 5000 kg/h for the fresh feed flow Q_{mp} (from 161750 kg/h to 166750 kg/h).

The simulation results have confirmed the functionality of the developed control structure when references and disturbances are modified. The functionality is demonstrated by the absence of stationary errors and by bringing the control temperatures at reference values, respectively. In the dynamic regime, the simulations have highlighted durations of the transient regimes under 20 s and overshoot under 2° C.

The overall performance (dynamic and stationary) indicate a superior behaviour of the developed control system compared with that base on conventional algorithms [13], in the conditions of on increased robustness.

Conclusion

The current paper presents a fuzzy control system of the reactor-regenerator for a catalytic cracking plant. Starting from deep knowledge of the process, membership functions have been generated and rules for elaborating commands have been formulated. The multivariable fuzzy controller has been integrated in a simulator by the use of which the performances of the proposed control structure have been tested. The simulations have highlighted compelling stationary and dynamic performance of the control system, proving the correctness of the assumptions which were bases of the fuzzy controller development. The results presented in this paper justify the development of the fuzzy control structures corresponding to other complex processes in to the chemical industry.

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