Intelligence based and Model based Controllers to the Interactive Thermal Process

R.Aruna
Department of instrumentation and control engineering
Kalasalingam University
India

M.Senthil Kumar
Department of instrumentation and control engineering
Kalasalingam University
India

D.Babiyola
Department of instrumentation and control engineering
Kalasalingam University
India

ABSTRACT
Now a day the control of chemical process is important craft in the industry. Mostly all the chemical process are highly nonlinear in nature this cause instability of the process. This paper deals with basic simulation studies on of the interactive thermal process. The Combination processes of Continuous stirred tank reactor (CSTR) and heat exchanger were controlled and the mathematical model was developed. This paper deals with the performance evaluation on the comparison of fuzzy control, adaptive control and conventional control in interactive thermal process. Fuzzy controller is one of the soft computing technique was proposed to control the process. In the design of adaptive control, Model reference adaptive control (MRAC) scheme is used, in which the adaptation law have been developed by MIT rule. Numerical calculation is used for steady-state analysis and dynamic analysis which is usually represented by a set of differential equations. A simulation is carried out using matlab. The control was performed to the combined process system using the fuzzy control scheme, the adaptive control algorithm and conventional controller method and its results were analyzed. Thus it shows that the fuzzy controller will be suitable for this process then the adaptive and conventional controller even without parameters change in the process. In a real world situation, these parameters could be estimated by using simulations or real execution of the system. Thus by controlling this process we recycle the waste heat and achieve less power consumption in the industries.

Keywords: - Process - CSTR & Heat Exchanger, PID controller, Adaptive controller, Fuzzy controller, Matlab.

1. INTRODUCTION
Chemical Engineering is a vibrant field that has undergone significant changes over the recent years. The extensive progress made in traditional areas such as transport phenomena, reaction engineering and unit operations has provided enough experience for chemical engineers to confidently venture into new areas such as life sciences, rational product design, and nano systems etc. Computational methods and associated tools are expected to play a very significant role in this revolutionary phase of chemical engineering.

In this paper, fuzzy control is employed for the stabilizing control, and a semi-physical simulation test system for thermal process is studied. A fuzzy control system is a control system based on fuzzy logic-a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 0 or 1 (true or false).

In common sense, 'to adapt' means to change a behavior to conform to new circumstances. Intuitively, an adaptive controller is thus a controller that can modify its behavior in response to the changing dynamics of the process and the character of the disturbances. The core element of all the approaches is that they have the ability to adapt the controller to accommodate changes in the process. This permits the controller to maintain a required level of performance in spite of any noise or fluctuation in the process. An adaptive system has maximum application when the plant undergoes transitions or exhibits non-linear behavior and when the structure of the plant is not known. Adaptive is called a control system, which can adjust its parameter automatically in such a way as to compensate for variations in the characteristics of the process it control.

The paper organized as follows: Section 2 present the brief description of the process to be controlled. In Section 3 an overview of Fuzzy controller design and in Section 4 the model reference adaptive system is outlined. Section 5 contains the Implementation of control system and its results.

2. PROCESS DESCRIPTION AND MODELING

The temperature control of a stirred-tank heater system was reported as a classical problem in chemical engineering. These problems are intended to utilize the basic numerical methods in problems which are appropriate to a variety of chemical engineering concepts. The complexity of the problem has been enhanced in the current study by changing simple tank to a reactor carrying out known reaction and also complete controller (Fuzzy, MRAC and PID) mechanism has been adopted. The analysis is extended further to stability of the system and optimization of the controller parameters along with a study on effect of reaction mechanism and other system parameters.

The graphical diagram of the interactive thermal process is shown in Figure 1.

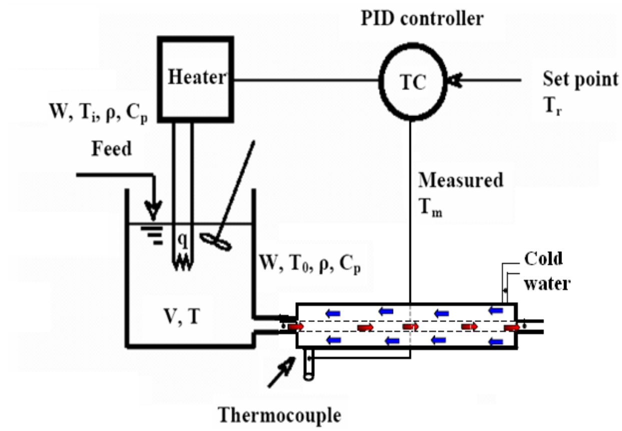

Figure 1. Interactive thermal process

A continuous stirred tank reactor with a non isothermal reaction A+B→Products and with first order rate equation ((-rA) = kCA) is considered. The tank has external heating coil with heat input Q (kJ/min) and the temperature is controlled by a controller in the closed loop feedback circuit as depicted in figure 1. The tank output is given as input to the heat exchanger. The counter-current tubular heat exchanger is used in this process. The inner pipe is a copper tube and the outer one is a stainless steel tube. The reactor hot fluid crosses the circular duct and the cold fluid (water) circulates in the annular duct. The thermocouple probes are placed at the outlet of cold fluid of the tubular heat exchanger. The flow rates of the fluids are constant. In this paper, the controlled variable is the fluid outlet temperature T and the manipulated variable is the heating coil Q.

The geometrical and physical parameters of the interactive thermal process are reported in Table's.

Table 1. Reactor parameter's value

Reactor parameters	Values
F/V,hr-1	4
Ko,hr-1	15e12
(-ΔH),BTU/lbmol	40000
E, BTU/lbmol	33500
ρCp, BTU/ft3	54.65
Tf, 'c	70
Caf, lbmol/ft3	0.132
UA/V	122.1

Table 2. Geometrical and physical parameter's of the heat exchanger

	L(m)	D(m)	a(m)	ρ(kg/m3)	Cp(J/kgK)
Inner	4.5	0.02	0.001	8900	394
Outer	4.5	0.04	0.003	7850	490

2.1 Overall material balance

The CSTR system is modeled using basic accounting and energy conservation principles.

Rate of material accumulation = rate of material in – rate of material out

$$dV\rho/dt = F_{in}\,\rho - F_{out}\,\rho$$

$$A\ dh/dt = F_i - F_o$$

Energy balance

$$V\rho Cp\,dT/dt = F_\rho Cp(T_i - T) + UA(Q - T)$$

Similarly energy balances for heat exchanger was developed

$$\rho_h Vol_h Cp_h \partial T_h/\partial t = Q_h Cp_h L\ \partial T_h/\partial x + h_h A_h (T_w - T_h)$$

$$\rho_c Vol_c Cp_c \partial T_c/\partial t = -Q_c Cp_c L\ \partial T_c/\partial x + h_c A_c (T_w - T_c)$$

$$\rho_w Vol_w Cp_w \partial T_w/\partial t = h_h A_h (T_h - T_w) + h_c A_c (T_c - T_w)$$

Thus combining the above set of energy balance differential equation the mathematical model for the interactive thermal process was obtained.

Where,

Ti : Inlet fluid flow temperature (◦C)

T : CSTR Tank Temperature (Controlled Variable) (◦C)

Tc :heat exchanger Outlet cold fluid flow temperature (◦C)

Th :heat exchanger Outlet hot fluid flow temperature (◦C)

Tw :heat exchanger separating wall fluid flow temperature (◦C)

Q : Rate of heat input to tank (Manipulated Variable) (kJ/min)

k : Reaction rate constant (min-1)

Fin : Fluid inFlow rate (kg/min)

Fout : Fluid outFlow rate (kg/min)

P : Fluid density of feed mixture (kg/m3)

Cp : Specific heat of liquid (kJ/kg K)

V : Reaction volume of the tank (m3)

3. FUZZY CONTROLLER DESGIN

The fuzzy control requires some simplification of the experimental model and human intervention is always necessary for the control of a process. Fuzzy logic provides a practicable way to understand and manually influence the mapping behavior. In general, fuzzy logic uses simple rules to describe the system of interest, rather than analytical equations, making it easy to implement. An advantage, such as robustness and speed, fuzzy logic is one of the best solutions for system modeling and control. A fuzzy control system is shown in figure 2.

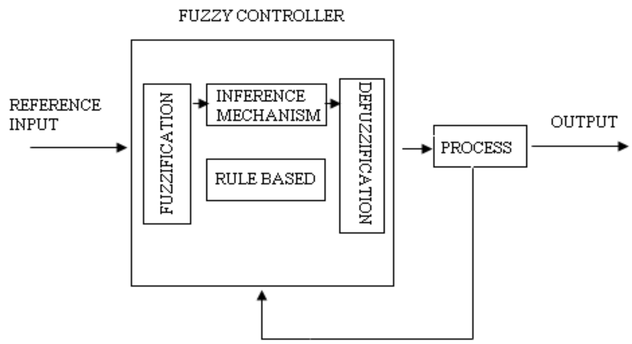

Figure 2. Fuzzy control system architecture

The first stage of fuzzy modeling is the selection of performance variables. Here the input and output variables of the interactive thermal process are selected. The goal is to find the input variables, which can be best discriminated, and are not affected by noise. In this paper, the fuzzy sets of two input as E and EC have different effects on the system at different stages of the control, the fuzzy control is modified by introducing two regulative factors. Input variables are the deviation E between the actual heat coil flow rate Q and its preset value, and the heat coil flow rate deviation rate EC. Output variable is the temperature ΔT.

By analyzing historical data, we choose basic domains for variables E, EC and ΔT. The word sets are defined as {NB, NM, NS, ZO, PS, PM, PB}, which donates negative big, negative middle, negative small, zero, positive small, positive middle, positive big, respectively.

The expert knowledge is formulated as a collection of If then rules and the associated memebership functions. In addition, the choice of membership functions(MFs) and rule base of the mamdani fuzzy controller will affect the performance of the system.

The number of fuzzy control rules was significantly reduced by combining related variables, and the control performance was greatly improved by adopting suitable rule base according to the angle of the pole with the vertical. In this paper, the initial linear relationship between input and output are described in 49 fuzzy-if-then rules which are represented in the format as Table 3.

Table 3. The rule base

E\EC	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

During the control process, we can look up the fuzzy control table to get ΔT directly by the values of deviation and deviation rate. Then we do defuzzification using the method of centre gravity, and multiply ΔT by a scale factor to get the ΔT as the set point value of the outlet temperature.

4. MODEL REFERENCE ADAPTIVE CONTROL

The model-reference adaptive system (MRAS) is an important controller. It may be regarded as an adaptive servo system in which the desired performance is expressed in terms of a reference model, which gives the desired response to a command signal. This is a convenient way to give specification for a servo problem.

The system has an ordinary feedback loop composed of the process and the controller and another feedback loop that changes the controller parameters. The parameters are changed on the basis of feedback from the error, which is the difference between the output of the system and the output of the reference model.

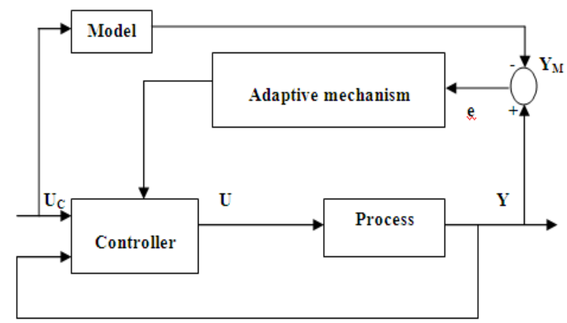

Figure 3. Model reference adaptive control

The mechanism for adjusting the parameters in a model-reference adaptive system can be obtained in two ways: by using a gradient method or by applying stability theory. The adaptation law uses the error between the process and the model output, the process output and input signal to vary the parameters of the control system. These the parameters varied so as to minimize the error between the process and the reference.

Adaptation law

The adaptation law attempts to find a set of parameters that minimize the error between the plant and the model outputs. To do this, the parameters of the controller are incrementally adjusted until the error has reduced to zero. A number of adaptation laws have been developed to date. The two main types are the gradient and the Lyapunov approach and we have use gradient approach.

5. CONTROL SYSTEM IMPLEMENTATION

This set provides the implementation of fuzzy controller, adaptive controller and conventional controller using Simulink. The first item that must be defined is the plant that is to be controlled. We have got the transfer function for the SISO systems as

The simplified transfer function model of the interactive thermal process given as:

$$Gp(s) = \underline{0.13 S + 4.79}$$

S2 + 8.38S + 13.4

The next step is to define the model that the plant must be matched to. To determine this model we must first define the characteristics that we want the system to have. Firstly we will arbitrary select the model to be a second order model of the form:

$$Gm(s) = \frac{\omega_n^2}{S^2 + 2\omega_n \xi S + \omega_n^2}$$

We must then determine the damping ratio ξ and the natural frequency ω_n to give the required performance characteristics. Thus the reference model was chosen to have a settling time of 3 seconds and a damping ratio of 0.707, which is an industry accepted standard.

$$Gm(s) = \frac{3.56}{S^2 + 2.67S + 3.56}$$

Note that we have defined the plant we need to develop a standard controller to compare with the adaptive controller. Controller setting is done using Ziegler-Nicholas technique and the best controller parameters are found to be Kc=0.58, Ki=1.2, Kd=0.18.

The following parameters are plotted on graph: plant output with fuzzy controller, adaptive controller and the conventional control.

Comparison of fuzzy controller, adaptive controller and conventional controller with a step input

Note that the model is complete; the first task we must perform is to compare the performance of the two controllers for a step input and no noise

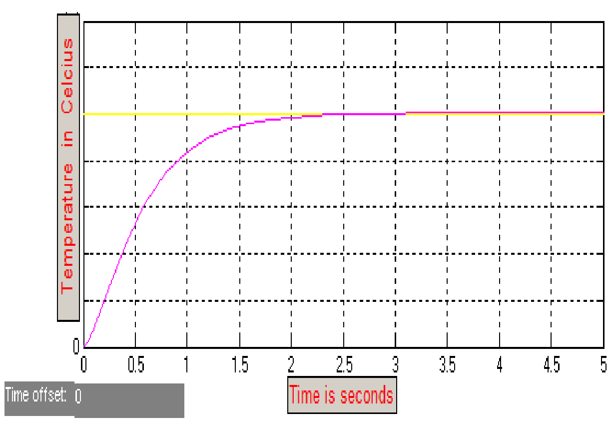

Figure 4. Plant output for fuzzy controller

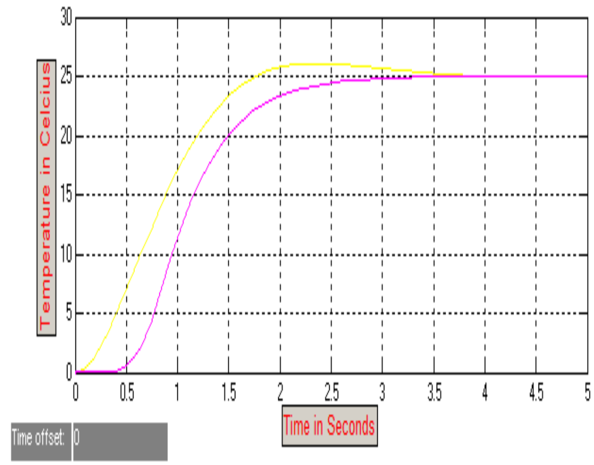

Figure 5. Comparison of Reference model output and Plant output with adaptive controller

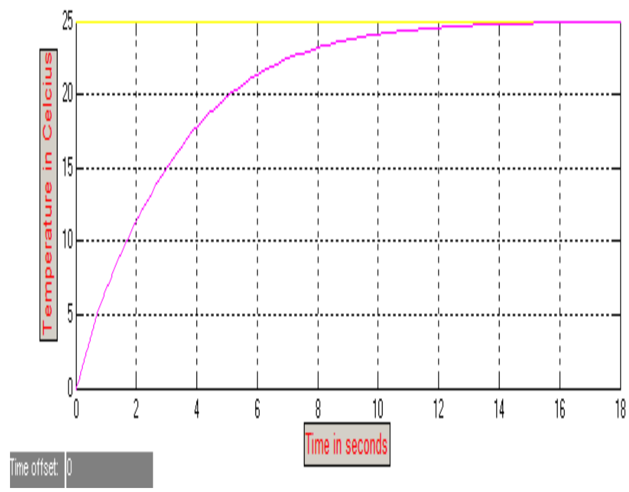

Figure 6. Plant output for conventional controller

Looking at figure 4, 5 and 6 fuzzy controller has less settling time compare to both adaptive and conventional controller. It takes fuzzy controller nearly 2.3 seconds and adaptive controller nearly 6.9 seconds to match perfectly the output of the reference model. However the conventional controller is matched with the input at 16 seconds. Thus the fuzzy controller is better for this process, compare to the both adaptive and conventional controller.

6. CONCLUSION

The paper demonstrated that while the conventional controller exhibits the process convergence time is typically large. To resolve these problems of adaptive controller, the proposed controller is redesigned by modifying the adaptation law. And the results show a significant improvement in the performance of the adaptive controller. Compare to adaptive controller, the fuzzy controller is better for this thermal process, since it has less settling time and no overshoot. The proposed controllers are tested by using Mat lab Simulink program and its performance is compared.

The simulations show that very good conversion can be achieved and at the same time the temperatures inside the reactor do not violate the safety constraints, even when there are large disturbances in the feed concentrations. The proposed process control system increases the safety of operations by reducing the impact from external disturbances. This will decrease the risk of unnecessary shutdowns of the process operation and also reduce the power consumption in industrial interactive thermal process by effective recycling of heat. In future this interactive thermal process will be tested with other controllers.

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