IOSR Journal of Engineering (IOSRJEN)
e-ISSN: 2250-3021, **p**-ISSN: 2278-8719
Vol. 3, Issue 7 (July. 2013), ||V1 || PP 09-15

Control Of Heat Exchanger Using Internal Model Controller

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Abstract: - Heat exchanger is a device that exchange the heat between two fluids of different temperatures that are separated by a solid wall. The temperature gradient or the differences in temperature facilitate this transfer of heat. In General, temperature control system has the characteristics of non-linearity, large inertia and time variability. It is difficult to overcome the effects of these factors and get the satisfactory results by using the normal PID controller. Therefore, the PI, FOPID, FUZZY and IMC are the controllers implemented in this paper to control the output temperature of the heat exchanger system. The PI, FOPID, FUZZY and IMC are the controllers are compared, based on their overshoot and settling time the conclusions are given using simulation results. As a future work FOPID controller tuned using genetic algorithm will be implemented in this paper later for better effective temperature control over other controllers.

Keywords: - Internal model based controller, PID controller, Fuzzy controller and Shell and tube heat exchanger system.

I. INTRODUCTION

In practice, all chemical processes involve production or absorption of energy in the form of heat. Heat exchanger is commonly used in chemical processes to transfer heat from a hot fluid through a solid wall to a cooler fluid. There are different types of heat exchanger used in the industry but most of the industry use shell and tube type heat exchanger system.

Shell and tube heat exchangers are probably the most common type of heat exchangers applicable for a wide range of operating temperatures and pressures. They have larger ratios of heat transfer surface to volume than double pipe heat exchangers and they are easy to manufacture in a large variety of sizes and configurations. A shell and tube heat exchanger is an extension of the double-pipe configuration. In shell and tube heat exchanger one fluid flows through the tubes and a second fluid flows within the space between the tubes and the shell [8].

This paper reports a work that considers a shell and tube heat exchanger. The outlet temperature of the shell and tube heat exchanger system has to be kept at a desired set point according to the process requirement. Firstly a classical PI controller is implemented in a feedback control loop so as to achieve the control objectives. PI controller exhibits high overshoots which is undesirable. To minimize the overshoot Fuzzy logic controller and internal model based controller is implemented. Fuzzy logic controller reduces the overshoot but it leads to the steady state error in the process. The internal model based controller design has gained widespread acceptance because it has only a single tuning parameter namely the closed loop time constant λ. The internal model controller reduces the overshoot and settling time. In this paper three types of controllers are designed to achieve the control objective and a comparative study between the controllers are evaluated.

II. SHELL AND TUBE HEAT EXCHANGER SYSTEM

A typical interacting chemical process for heating consists of a chemical reactor and a shell and tube heat exchanger system. The super-heated steam comes from the boiler and flows through the tubes. Whereas, the process fluid flows through the shells of the shell and tube heat exchanger system. Different assumptions have been considered in this paper. The first assumption is that the inflow and the outflow rate of fluid are same. The second assumption is the heat storage capacity of the insulating wall is negligible. A thermocouple is used as the sensing element which is implemented in the feedback path of the control architecture. The temperature of the outgoing fluid is measured by the thermocouple and the output of the thermocouple is sent to the transmitter unit, which eventually converts the thermocouple output to a standardized signal in the range of 4-20 mA. This output of the transmitter unit is given to the controller unit. The controller implements the control algorithm, compares the output with the set point and then gives necessary command to the final control element via the actuator unit. The actuator unit is a current to pressure converter and the final control unit is an air to open valve. The actuator unit takes the controller output in the range of 4-20 mA and converts it in to a standardized pressure signal in the range of 3-15 psig. The valve actuates according to the controller decisions.

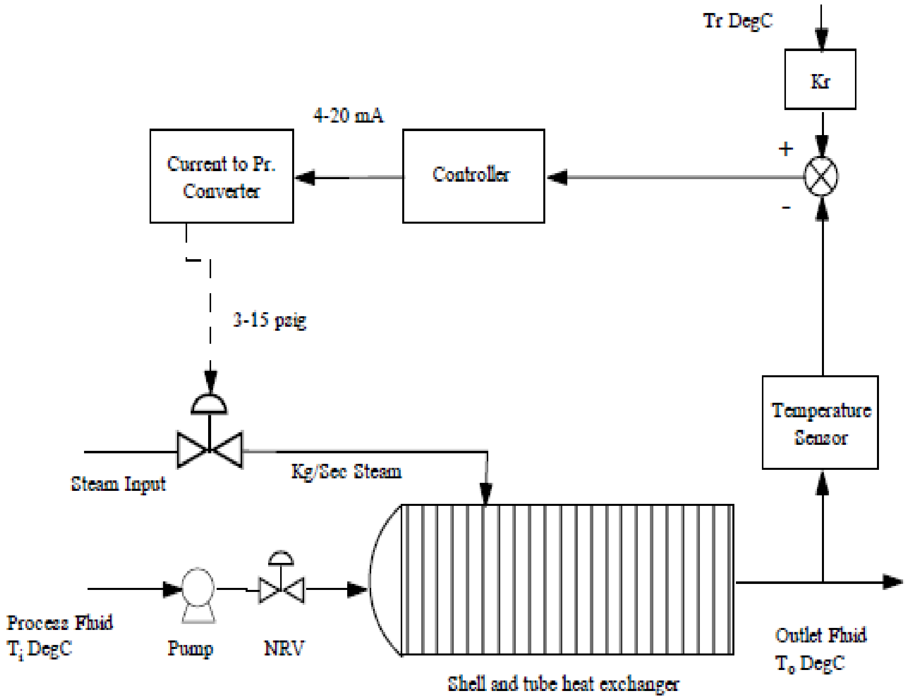

Fig.1 Shell and tube heat exchanger system control scheme

There can be two types of disturbances in this process, one is the flow variation of input fluid and the second is the temperature variation of input fluid. But in practice the flow variation of input fluid is a more prominent disturbance than the temperature variation in input fluid.

III. MATHEMATICAL MODELING

In this section the heat exchanger system, actuator, valve, sensor are mathematically modelled using the available experimental data. The experimental process data's are summarized below [3].

Exchanger response to the steam flow gain 50°C/(kg/sec)
Time constants =30 sec
Exchanger response to variation of process fluid flow gain =1 °C/ (kg/sec)
Exchanger response to variation of process temperature gain = 3°C/°C
Control valve capacity for steam = 1.6 kg/sec
Time constant of control valve = 3 sec
The range of temperature sensor = 50°C to 150°C
Time constant of temperature sensor = 10 sec
From the experimental data, transfer functions and the gains are obtained as below.

Transfer function of process = $50e^{-s}/30s+1$
Gain of valve = 0.13
Transfer function of valve = 0.13/3s+1
Gain of current to pressure converter = 0.75
Transfer function of disturbance variables
Flow =1/30s+1
Temperature =3/30s+1
Transfer function of thermocouple = 0.16/10s+1

To control the exit temperature of the heat exchanger system a classical feedback controller is used. The PI control algorithm remains the most popular approach for industrial process control despite continual advances in control theory. This is not only due to the simple structure which is conceptually easy to understand and, which makes manual tuning possible.

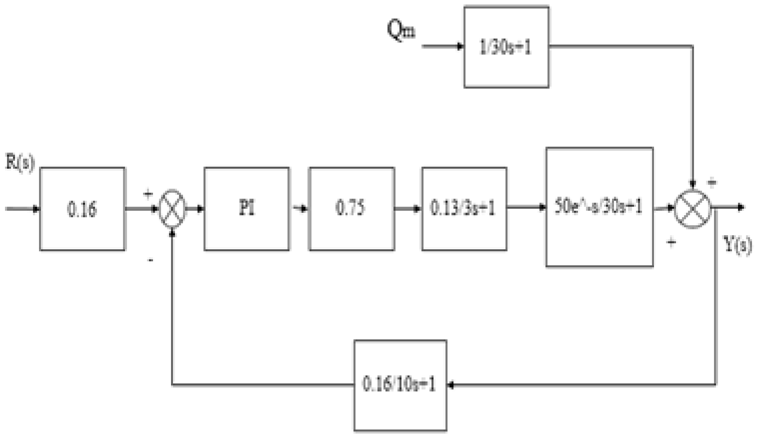

Fig.2 Feedback control of shell and tube heat exchanger system

The PI tuning rule used here is Zeigler – Nicholas tuning rule because it provides simple tuning formulae to determine the P, PI and PID controller parameters [4]. According to Z - N tuning criteria the obtained Ku & Pu are 16.57 and 32.5 respectively. For the PI controller in the heat exchanger, the values of tuning parameters obtained are Kp = 7.53, Ti = 27.08. Usually, initial design values of PI controller obtained by all means needs to be adjusted repeatedly through computer simulations until the closed loop system performs or compromises as desired.

IV. IV. FUZZY LOGIC CONTROLLER

The design of fuzzy logic controller consists of several steps. First, the variables for the fuzzy control system are determined. The universe of Discourse for all the variables involved are then set. Here, the fuzzy controller is designed with two input variables and one output variable. The input variables are error and change in error that is difference between the set point temperature and the actual temperature (error-'e') and the rate of change of error (de) and output is controller output (co).

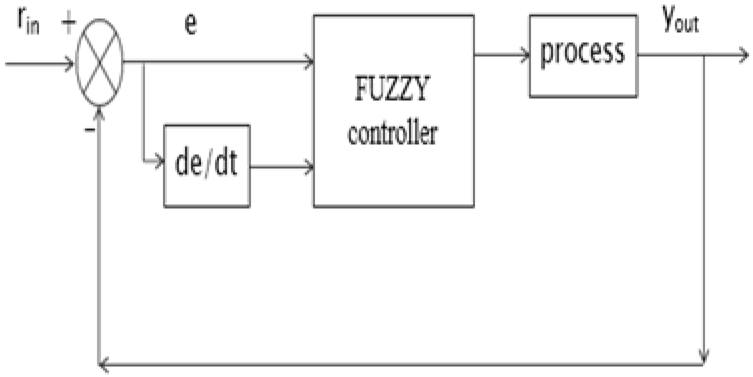

Fig.3 structure of fuzzy logic controller

The above figure shows the fuzzy logic controller to control the temperature in the outlet of the shell and tube heat exchanger system with error and change in error as input [2]. once a step change of flow is given at shell side it directly affects the heat transfer rate between the two fluids in shell and tube side , lesser the flow greater is the heat transfer between fluids . Both the input variables and the output variable is designed using five membership functions. The linguistic terms associated with variables are very low (VL), low (L), medium (M), high (H), very high (VH). The rule base developed for this system is based on MAXMIN inference[9]. That is MIN is used for the AND conjunction and MAX is used for the OR conjunction. For this system MIN conjunction is used.

TABLE I

		CHANGE IN ERROR				
		VL	L	M	H	VH
ERROR	VL	L	VL	L	VL	L
	L	L	M	L	VL	L
	M	M	M	L	M	L
	H	H	H	VH	H	M
	VH	H	VH	VH	H	

Rule base Matrix

V. INTERNAL MODEL CONTROLLER

Internal model controller provides a transparent framework for control system design and tuning. The main feature of internal model controller is that the process model is in parallel with the actual process. The transfer function of the process is shown below

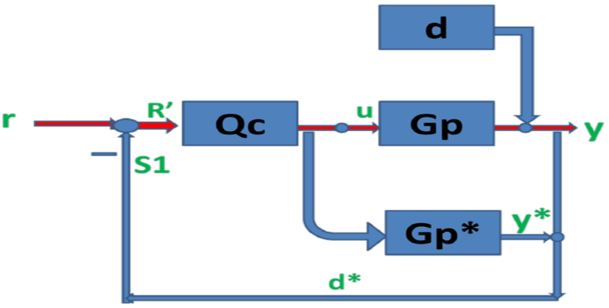

Fig .4: Internal model controller

$$G_p(s) = \frac{5e^{-s}}{90\,s^2 + 33s + 1}$$

The process model Gp (s) is factored in to two parts, that is invertible part Gp-(s) and non-invertible part $Gp_+(s)$, The non-invertible part consists of RHP zeros and time delays. This factorization is performed so as to make the resulting internal model controller stable. Several methods of tuning of internal model controller and efficient calculation of filter parameter have been proposed in literature [1, 5, 6, and 7].

$$\widetilde{G_p} = \tilde{G}_{P-}(s)\tilde{G}_{P+}(s)$$

$$\tilde{G}_P(s) = \frac{5}{(30s+1)(3s+1)(0.083s^2+0.5s+1)}(-0.083s^2 - 0.5s + 1)$$

$$Q(s) = \tilde{G}_{p-}^{-1}(s)f(s)$$

$$Q(s) = \frac{(30s+1)(3s+1)(0.083s^2+0.5s+1)}{5}\frac{1}{(\lambda s+1)^4}$$

In practice λ is taken higher than the time constant value. So, the values of λ is obtained as 11.4. Substituting the value as 11.4 in the above equation we get the transfer function of internal model controller denoted by Q(s).

$$Q(s) = \frac{1.494s^4 + 603s^3 + 235.966s^2 + 6.7s + 0.2}{16.889.6\,s^4 + 5926.17s^3 + 779.76s^2 + 45.6s + 1}$$

VI. FOPID CONTROLLER

PID controllers have been used for several decades in industries for process control applications. The reason for their wide popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow process plants [1]. The performance of the PID controllers can be improved by making use of fractional order derivatives and integrals. This flexibility helps to design more robust control system. In fractional order PID (FOPID) controller, the integral and derivative orders are usually fractional. In FOPID besides Kp, Ki, Kd there are two more parameters λ and μ, the integral and derivative orders respectively. If λ =1 and μ =1, then it becomes integer PID. If and μ are in fractions then it becomes fractional order PID.

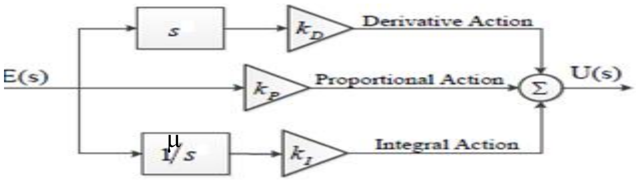

Fig.5: Block-diagram of FOPID controller
λ

The transfer function of such a controller has the form

$$G_{FOPID} = \frac{u(s)}{e(s)} = k_p(1 + \frac{1}{k_i s^{\lambda}} + k_d s^{\mu})$$

It can be expected that the $PI^{\lambda}D^{\mu}$ controller may enhance the systems control performance. One of the most important advantages of the $PI^{\lambda}D^{\mu}$ controller is the better control of dynamical systems, which are described by fractional order mathematical models. Another advantage lies in the fact that the $PI^{\lambda}D^{\mu}$ controllers are less sensitive to changes of parameters of a controlled system .This is due to the two extra degrees of freedom to better adjust the dynamical properties of a fractional order control system.

VII. VI. SIMULATION AND TESTING

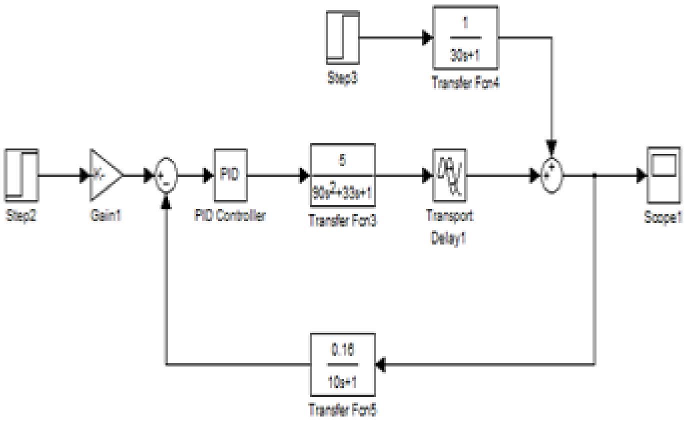

Fig. 6: Simulink model of feedback PI controller

The simulations for the different control mechanism discussed above were carried out in Simulink and the simulation results have been obtained.

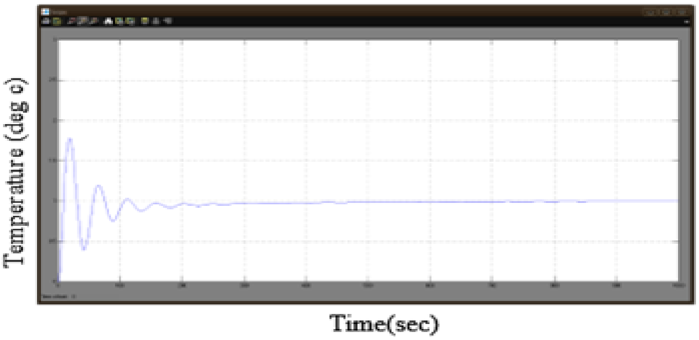

Fig.7 Response of PI controller

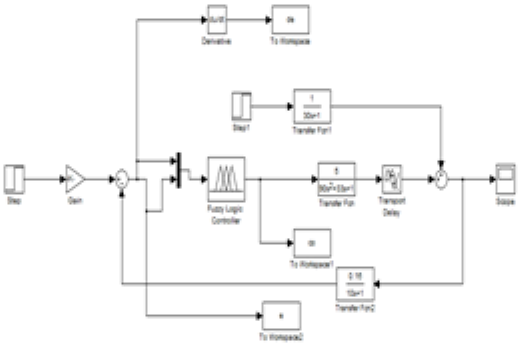

Fig .8: Simulink model of fuzzy logic controller

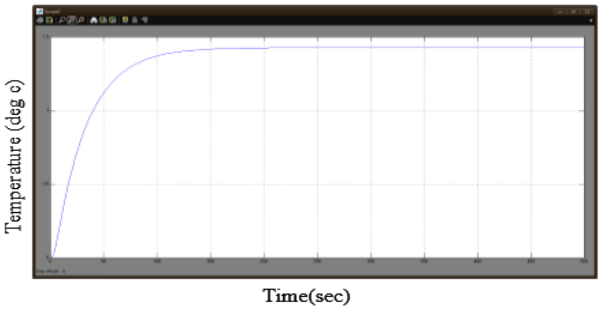

Fig.9 Response of fuzzy controller

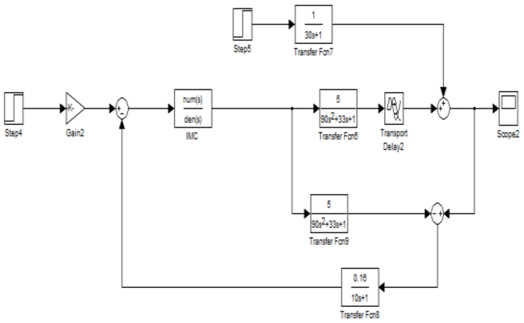

Fig .10: Simulink model of internal model controller

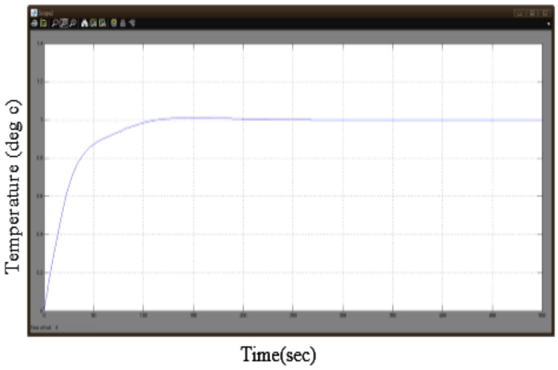

Fig.11 Response of IMC controller

Figure 11 shows the unit step response of the shell and tube heat exchanger system when an internal model controller is implemented in the series of the real process and an approximate model of the process is placed in parallel of the real process. The step response shows less overshoot and steady state error from feedback PI controller and fuzzy logic controller.

VIII. RESULTS AND DISCUSSION

To evaluate the performance of the different controllers this paper has considered two vital parameters of the step response of the system. The first parameter is the maximum overshoot and the second parameter is the settling time. Compared to PI, FOPID and Fuzzy logic controller internal model based controller performs well and give the effective control.

IX. CONCLUSION

This paper takes a case study of shell and tube heat exchanger system and evaluates different methods to control the outlet fluid temperature. four different controllers are designed to control the outlet temperature of fluid and the performances of these controllers are evaluated by one of the methods for performance evaluation is the time domain analysis of overshoot and settling time. This paper takes the process model to be the same as the process, which is practically impossible to achieve. So as a further work FOPID controller tuned using genetic algorithm will be implemented for effective temperature control of the heat exchanger system.

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