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Real-Time Temperature Control of a Shell and Tube Heat Exchanger by IMC based PID controller

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Abstract

Shell and Tube Heat Exchanger is most widely used and most efficient heat exchanger in industries. 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 by using controllers. Many controllers such as PID, feedback plus feed forward, Fuzzy logic, Internal Model based PID controller are used to control the temperature. The control system objective is to control the hot fluid outlet temperature by manipulating the inlet cold fluid flow rate. The transfer function of the shell and tube heat exchanger process is obtained using energy balance equations. Designing of the PID Controller is done by conventional Cohen-Coon tuning method and advanced IMC method. The closed loop results are obtained using PID controller both Cohen-Coon method and IMC method. The closed loop responses for various set point changes in hot fluid outlet temperature and disturbance in inlet temperature of cold fluid are studied. The experiment and MATLAB simulations are carried out by using the above parameters of CC-PID and IMC-PID and the data are noted for different set points. Comparison is made between the results of both the experiment and simulations. And the compared the results of Cohen-Coon method and IMC tuning method. On comparing the results, we can demonstrate that IMC based PID controller gives better responses in terms of lesser overshoot and faster settling time. The present work emphasis is about the experimental demonstration of advanced controller such as Internal model controller (IMC) to a general process such as shell and tube heat exchanger control.

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1 Introduction

A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical

plants, petroleum refineries, natural-gas processing, and sewage treatment. Subhransu et al., [1] worked on the comparison of IMC controller and IMC based PID controller. Firstly, the mathematical modeling of the system is done by using the experimental data. IMC based PID controller studies are carried out. Simulation results are obtained. Overshoot and settling time is found less in case of IMC based PID controller.

Rajalakshmi and Mangaiyarkarasi [2] studied the Shell and tube heat exchanger in which the outlet temperature has to be kept at a desired set point. Firstly, the heat exchanger system, actuator, valve, sensor are modeled using experimental data. This paper evaluated the methods to control the outlet fluid temperature where different types of controllers like feedback PI, fuzzy logic controller, Internal model controller were simulated and tested. The two parameters (Overshoot, Settling time) of the step response of the system are compared with the controllers used. Internal model controller performed effectively by showing less overshoot and settling time compared to feedback PI and fuzzy logic controller.

Subhransu Padhee [3] analysed the performance of different controllers like feedback PID, feedback plus feedforward PID, Internal model controller to regulate the temperature of outlet fluid temperature. Firstly here the system configuration is introduced and mathematical modeling of the system is done by using experimental data. Simulation for control techniques is done and results are evaluated. The best results were seen in Internal model controller with minimum Overshoot, settling time and less value of error indices compared to other two different control techniques.

Rakesh et al., [4] studied mainly on the comparative analysis of the response for the heat exchanger system using Internal model controller and Internal model based PID controller. In this paper they discussed on different control strategies like model perfect & no disturbance with tuning parameter, model perfect with disturbances using tuning parameters and disturbance rejection with tuning parameter. Simulation is done with IMC controller. IMC based PID controller has very less settling time, less set-point tracking and less offset error. By increasing the tuning parameter value the settling time also increases which increases the set-point tracking is observed in this paper.

Saranya et al., [5] studied simulations for fuzzy logic, IMC controllers for a heat exchanger. By comparing the results of all the controllers, we observe the better results in both IMC and fuzzy logic controllers. Overshoot is less in fuzzy logic controller than the other two and settling time is less in IMC controller than the other two. In future for obtaining better results we can combine both fuzzy and neural network controllers i.e., Neuro -fuzzy or by combining IMC and fuzzy i.e., fuzzy-IMC controllers.

Sahoo et al., [6] presented the work on modeling and control of heat exchanger using system identification method. The Auto Regressive– Moving-Average model with exogenous inputs (ARMAX) is model of the heat exchanger. The experimental results show that the IMC- based PID controller makes the system reach the desired set point earlier than relay auto tuned PID controller. In both the regulatory responses, it can be observed that the system responds to the disturbance earlier and returns to set point faster in the case of IMC-based PID controller than relay auto tuned PID controller. However, hot water outlet temperature may be selected as controlled variable rather than control of cold water outlet temperature.

Gopi Krishna Rao [7] presented the work on the internal model control (IMC) and proportional integral derivative (PID) controller. Tuning rules provide an excellent tracking of set-point, but

sluggish disturbance rejection, as the conventional IMC filter introduces slowprocesspole. Disturbance rejection is significant than set-point tracking in many industrial applications.

Ujjwal et al., [8] presented the design of Internal model control (IMC) based proportional integral derivative (PID) controller design. Especially, the design of the IMC controller for integrating and unstable processes is really a challenging task and hence widely explored by researchers. In this study, a brief review is provided on IMC-PID tuning for various classes of single input single output (SISO) processes along with a table containing their tuning relations. In addition, IMC controllers with adaptive, auto-tuning, and fractional-order structure have also been discussed here. However, in practice most of the industrial processes are multi input multi output (MIMO) in nature and hence, this review also includes significant discussions on IMC tuning strategies for MIMO processes. Real-time implementations of IMC techniques reported in the literature are also discussed. Finally, a comparative study is provided through real-time experimentation on a coupled tank system.

Abdelaziz Fellah and Ajay Band [9], presented a very useful learning approach for teaching recursion and highlighting the importance of recursive thinking and abstraction skills in problem solving through a well-defined sequence of steps. Aziz Fellah and Ajay Bandi,[10] presented a very important approach through a real-time Internet of Things (IoT) as a case study.

2 Description of the process

The experimental setup consists of 1- shell, 1- tube pass type heat exchanger (Figure 1). Two reservoirs of fluid are provided for cold and hot fluids. A Rota meter to measure the cold fluid inlet flow rate and another Rota meter for hot fluid inlet is arranged. Temperature sensors are arranged at respective positions of cold fluid inlet, outlet and hot fluid inlet and outlet. Two heaters of 3 kW capacity are used. All the elements are connected to computer for automatic functioning thereby different actions are carried out by simply giving commands through the computer.

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.

Figure 1: Photograph of a computer control of a Shell and Tube heat exchanger

The entire unit consists of:

Heat exchanger(1:1 pass)

Shell: inner diameter = 210mm, Outer diameter = 225mm,
Tubes: Inner diameter = 15mm
Outer diameter = 17mm, No of tubes= 18, Triangular pitch = 35mm

Heater:
Type: Industrial
No. of coils/heaters = 2 , Wattage = 3KW

Control valve:
Body form: globe
Design: 13, Size of valve: 1" , Gland packing: Teflon, On supply failure: valve closes.Type: diaphragm + spring, Supply tank: (500x760x400) mm^3
Measuring tank: 500mmx350mmx350mm

3 Mathematical Model

Unsteady state energy balance:

Tube side:

$$V_t \rho C_p \, dT_{to}/dt = W_t \rho C_p(T_{ti} - T_{to}) + UA (T_{so} - T_{to}) \quad (1)$$

Shell side:

$$V_s \rho C_p \, dT_{so}/dt = W_s \rho C_p (T_{si} - T_{so}) - U A (T_{so} - T_{to}) \quad (2)$$

Transfer function Model :

$$G_p(s) = T_{so}(s)/W_t(s) = K_p/[(\tau_1 s+1)(\tau_2 s+ 1)] \quad (3)$$

= (Hot fluid outlet temperature) /(Cold fluid flow rate)

With substitution of heat exchanger data, we obtain,

$$Gp(s) = T_{so}(s)/W_t(s) = 166/[(0.1408\,s+1)(4.1404\,s+1)] \qquad (4)$$

$$Gp(s) = kp\, e^{-\tau ds}/(\tau s+1) = 166\, e^{-0.214}/(2.14S+1) \qquad (5)$$

Where, $\tau = (\tau_1+\tau_2)/2=2.14$, $\tau d = 0.1\ \tau =2.14$, $kp = 166$

4 Design of IMC based PID controller

For the above first order time delay model, the PID parameters of IMC controller are obtained from the references [11] as,

$$K_c = (2\tau+\tau_d)/[2(\lambda+\tau_d)],\ \tau_I = \tau + \tau_d/2,\ \tau_D = \tau\,\tau_d/[2(\tau+\tau_d)] \text{ and } \tau_1 = \lambda\,\tau_d/[2(\lambda+\tau_d)] \qquad (6)$$

By substituting τd,τ, λ (tuning parameter) = 2 values in the above equations we get Kc ,τ_I, τ_D. and

effect of τ_1 is neglected and it gives, $K_I = Kc / \tau_I$, $K_D = Kc * \tau_D$.

PID Design parameters:

$$Kc = 1.0149,\ K_I = 0.4516,\ K_D = 0.1049 \qquad (7)$$

4.1 Design of Cohen-Coon based PID parameters :

The PID parameters are obtained from references [11] as

$Kc = 1.8$, $\tau_I=2.247$, $\tau_D=0.1019$

From these parameters we get
$K_I = k_c/\tau_I$, $K_D = k_c * \tau_D$ and it gives $K_c = 1.8$, $K_I =0.801$, $K_D = 0.1834$ (8)

5 Results and Discussion

The closed loop simulation and experimental results are presented here. The Closed loop simulations are carried out using Simulink/MATLAB model (Figure 2) for both IMC based PID and CC based PID controllers (Eq.(7) and Eq.(8))

The closed loop responses in hot fluid outlet temperature and control action in cold fluid flow rate for CC based PID and IMC based PID controller are obtained. For a set point change from 50 to 45 °C, the simulated response of IMC based PID is faster than CC based PID as shown in Figure 3 The Experimental response is shown in Figure 5 for a set point change of 50 to 45 °C, it gives faster response and validates the superior performance of IMC based PID controller. As hot fluid outlet temperature decreases (controlled variable) from 50 to 45 ° C, the control actions in terms of cold fluid flow rate (manipulated variable) increases and reaches steady state, which are shown in Figure 4 (Real-Time) and Figure 6 (simulations).

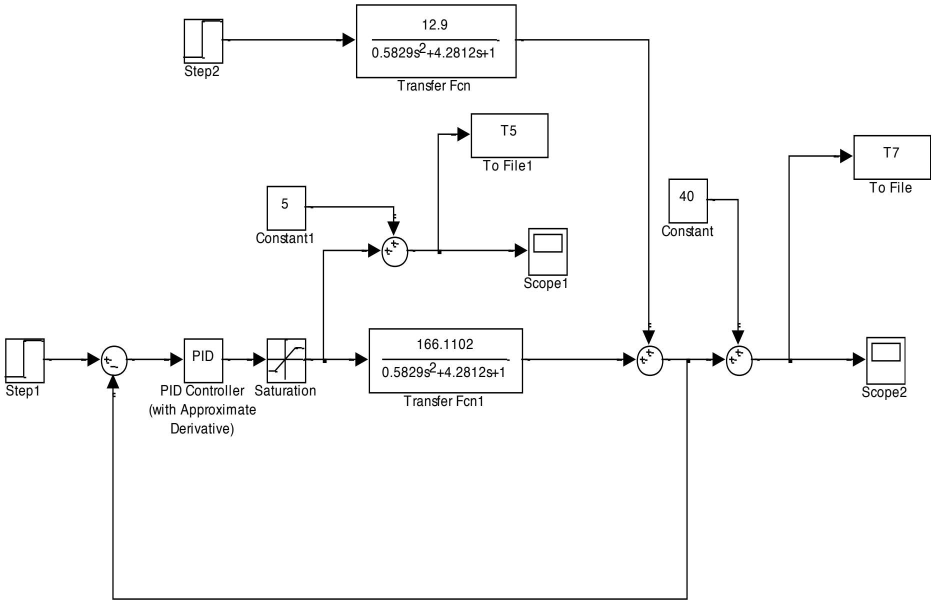

Figure 2: Simulink Model for closed loop control studies of CC-PID and IMC-PID for a Shell and tube heat exchanger

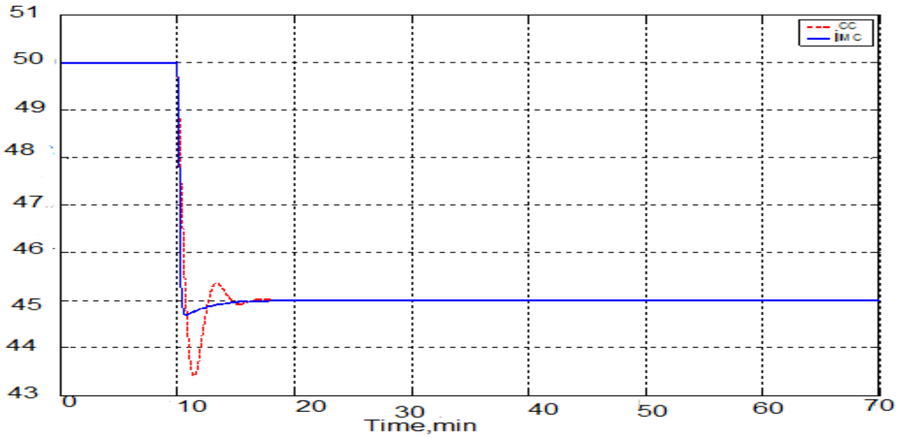

Figure 3 : Comparison of closed loop responses (Simulation) in outlet temperature of hot fluid of CC and IMC for set pointchange from 50 to 45 °C

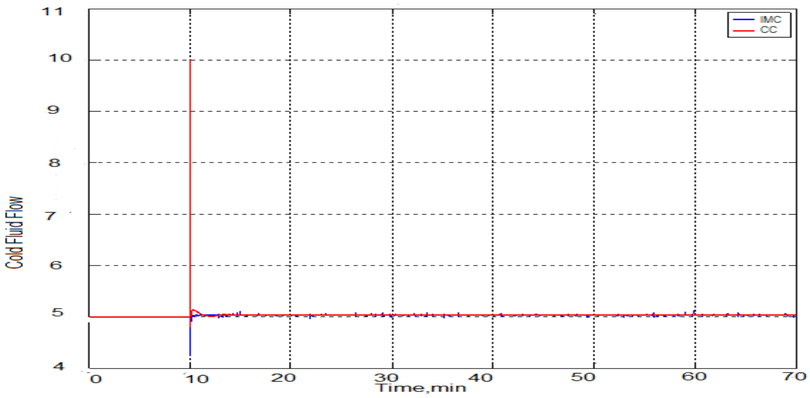

Figure 4 : Control actions (Simulation) in cold fluid flow rate of CC and IMC for the response shown in Figure 3

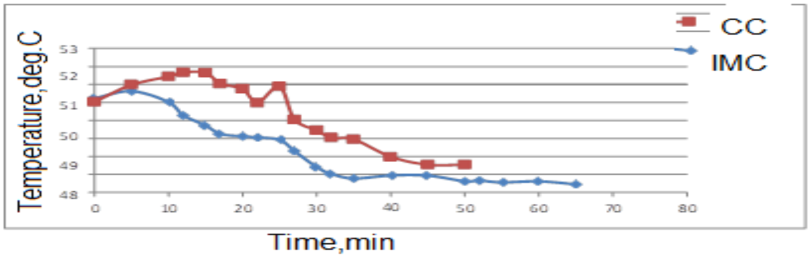

Figure 5 : Comparison of Experimental responses in outlet temperature of hot fluid of CC and IMC

for a set point change from 50 to 45 °C

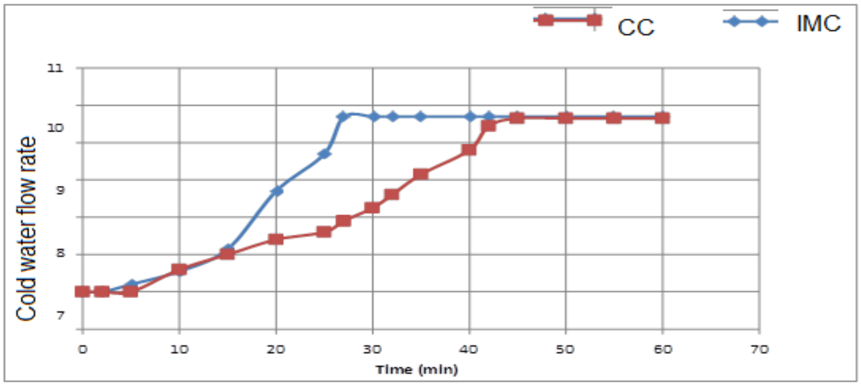

Figure 6 : Experimental control actions in cold fluid flow rate (Manipulated variable) of CC (Red) and IMC (Blue) for the response shownin Figure 5

6 Conclusions

In the present work, it has been demonstrated that the superior performance of internal model control technique by experimental study which validates simulation study. The outlet temperature of hot fluid of Shell and tube heat exchanger is controlled by IMC based PID controller for different set points by using coolant fluid flow rate (Manipulated Variable) and comparison is made with conventional PID controller (Cohen –Coon). Closed loop control studies are performed on Shell and tube heat exchanger in real time mode and through MATLAB Simulations. Advanced IMC based PID controller is found to be better than conventional CC based PID controller in terms of lesser overshoot and lesser settling time in both real time studies and through simulations.

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