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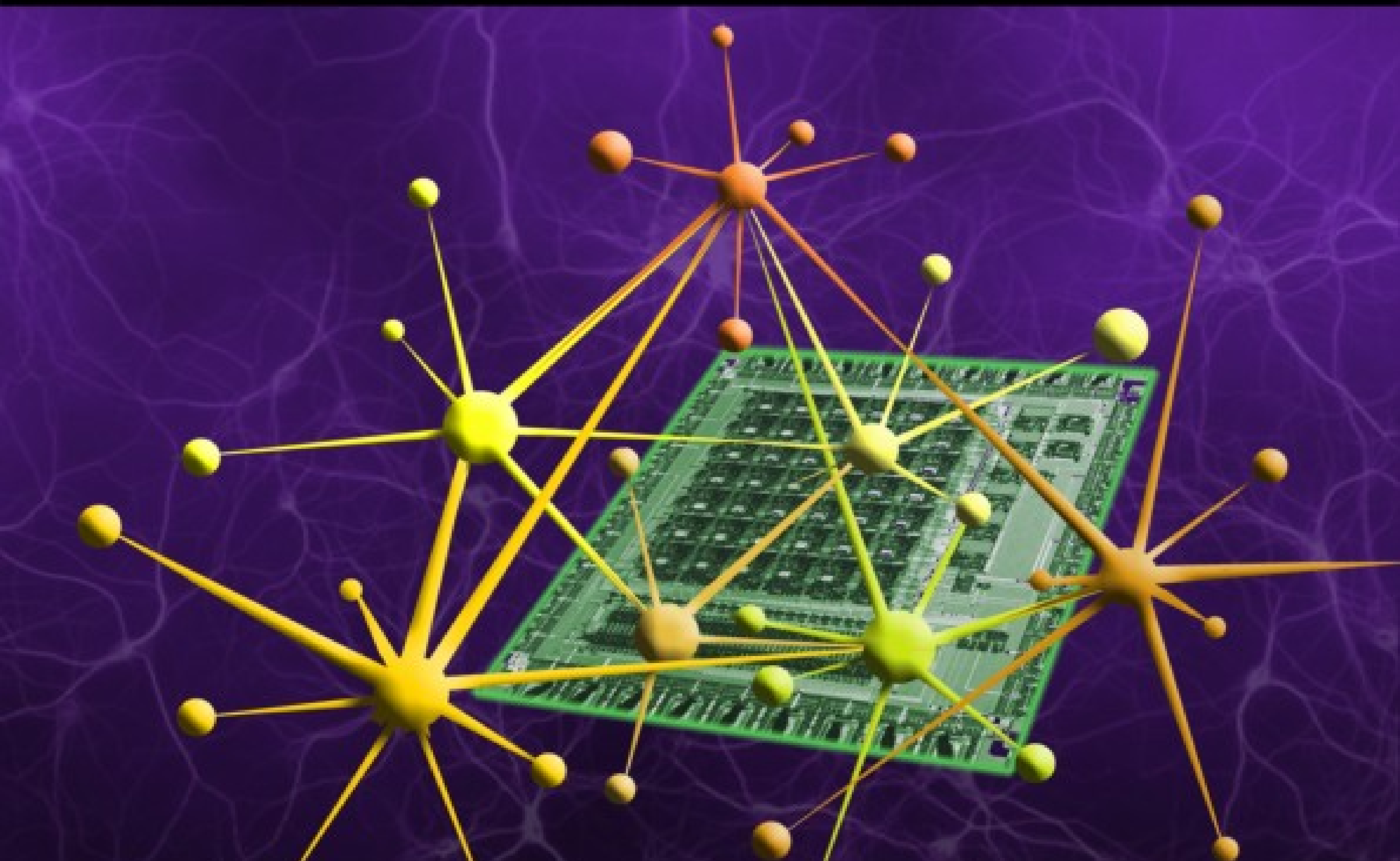

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Model Based Controller Design for Shell and Tube Heat Exchanger

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Abstract: In all the process industries the process variables like flow, pressure, level and temperature are the main parameters that need to be controlled in both set point and load changes. The transfer of heat is one of the main important operation in the heat exchanger .The transfer of heat may be fluid to fluid, gas to gas i.e. in the same phase or the phase change can occur on either side of the heat exchanger. The control of heat exchanger is complex due to its nonlinear dynamics. For this nonlinear process of a heat exchanger the model is identified to be First Order plus Dead Time (FOPDT).The Internal Model Control (IMC) is one of the model predictive control methods based on the predictive output of the process model. The conventional controller tuning is compared with IMC techniques and it found to be suitable for heat exchanger than the conventional PI tuning. *Copyright © 2007 IFSA.*

Keywords: Process modeling, FOPDT, Controller, Internal model control, Heat exchanger

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1. Introduction

Nonlinear control is particularly important in the process industries because chemical processes are generally nonlinear. Most current nonlinear controller design methods are based on state feedback. However, they cannot be applied to many process control problems where the complete information is not available [1]. A heat exchanger is a device that is used to change the temperature distribution of two fluids, particularly in process industries, and many heat exchangers being manufactured are basically open loop systems, so the performance of the heat exchanger is determined by its fixed structural and mechanical design. In practice, if the temperature distribution, i.e. the performance of a heat exchanger, deviates beyond the accepted tolerance of the practical requirement, the solution is to replace the worn heat exchanger by a new one because of the lack of a suitable model for feedback control design, since modeling a heat exchanger for dynamic analysis and control design is not an easy task [2]. The control of heat exchanger is a complex process due to its nonlinear dynamics, steady state gain and time constant with process fluid [3]. Dugadale and Wen [4] discussed about the controller optimization of tube type heat exchanger. Katayama et al. [5] proposed a method of optimal tracking control of heat exchanger with change in load condition.

The selection of good control algorithm depends upon the performance comparison of different possible control techniques and selecting the best for the desired condition. To achieve the above for the dynamically changing process the controller parameter should perfectly match with the parameter. A control system designed for a particular process should provide fast and accurate changes for both the set point changes as well for a load changes. Model based controllers are now popular because its ability to handle a process with dead time. One type of model based control is Internal Model Control (IMC) which is having both for open loop and closed loop system. IMC tuning is referred to a set of tuning procedures based on the internal model principle. The underlying idea behind internal model methodologies is to compute a controller and/or to set its values relative to a prescribed response formulated as a prescribed (internal) model. In this way, IMC designs belong to the class of model-based control settings, whose origin can be traced back to the Proportional- Integral-Derivative (PID) tuning method proposed by Dahlin [6]. In the process control field, there has been some work along these lines, including the IMC Proportional-Integral (PI)/PID tuning by Rivera et al[7] and Smith and Corripio's [8] direct synthesis tuning rules. Existing IMC tuning guidelines for typical processes have been surveyed by Chien and Fruehauf [9]. Morari and Zafiriou introduced the IMC for process control systems [10].It is based on the predictive output of the process model. Kaya have proposed a model based controller for a relay feedback system [11]. Tan et al. [12] have proposed an IMC structure for an unstable process with time delay.

In this paper, the design of IMC control structure for the shell and tube heat exchanger is implemented. The heat exchanger used is a fluid-fluid double pipe countercurrent type. The mass flows of the two streams, inlet temperature of the two streams and outlet temperature of the two streams are the process variables associated with the function of each exchanger. Four of these variables are independent, and the values of the other two follow from these four. While theoretically any four of the variables can be independent, in most practical cases the flow rates and the inlet temperatures are determined by external circumstances. Therefore, the outlet temperatures become the output variables. One of these two outlet temperatures is the controlled variable, and the flow rate of the other stream is the manipulated variable. Hence here the hot fluid temperature is taken as controlled variable and cold fluid flow rate is taken as manipulated variable [13].In this work the process dynamics are modeled from a step response analysis by changing the cold fluid flow rate at different hot fluid inlet temperature. For the developed model an IMC control structure is designed and its performance measure is based on rise time, settling time and various performance indices are compared with conventional PI controller.

2. Experimental Setup

The shell and tube heat exchanger setup is shown in the Fig. 1. Here a fluid-fluid double pipe countercurrent type heat exchanger is used. The hot fluid flows from the tank T2, enters to the shell side of the heat exchanger. Using the heater H particular operating temperature is maintained. From tank T1, cold fluid flows into the tube side of the heat exchanger. The objective here is to maintain the hot fluid temperature which is taken as controlled variable. The cold flow rate is given as step change variation that is considered as manipulated variable. Table 1 gives the components used in the experimental setup.

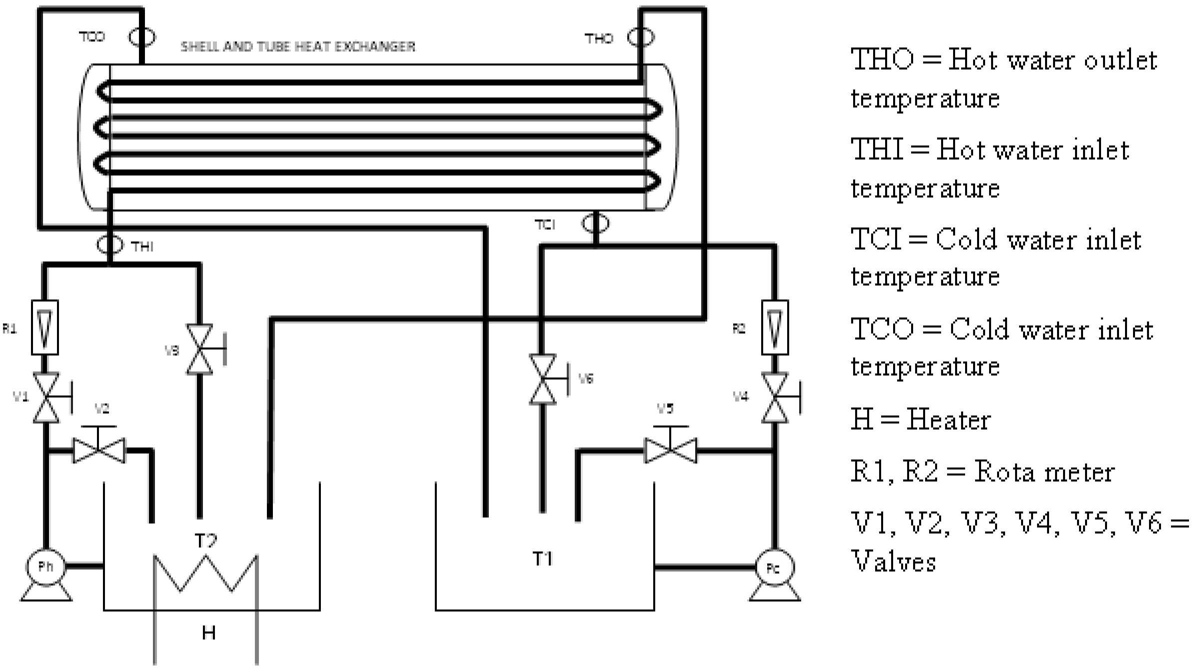

Fig. 1. Experimental setup.

Table 1. Components specifications of experimental Setup.

Component	Specifications
Shell side	Inside diameter 220 mm, Baffle Spacing 125 mm, Passes 1
Rota meter	3 – 30 LPM
Pumps	0.5 HP
Hot Water Bath	70 Liters
Thermocouple	PT – 100 RTD
Pitch	Triangular Pitch, Clearance between tubes 7 mm, Tube Pitch 15 mm

3. Model Identification

For the purpose of designing an IMC controller, the dynamics of the process are described by first order plus dead time (FOPDT) model [14].The FOPDT model parameters are found from the experimental data. The graphical method i.e. two point method [15], the time constant and time delay are calculated as follows.

$$\tau = 1.5(t_{63.2\%} - t_{28.3\%}) \tag{1}$$

$$\tau_D = t_{63.2\%} - \tau \tag{2}$$

It seems to be the heat exchanger exhibits a FOPDT model and system is non linear. The transfer function for a step input change is given by equation (3)

$$G(s) = \frac{1.8e^{-5.6s}}{(15s+1)} \tag{3}$$

4. Internal Model Control

Internal model control is model based controller. The Fig. 2 shows the IMC structure which makes use of a process model to infer the effect of immeasurable disturbance on the process output and then counteracts that effect. The controller consists of an inverse of the process model.

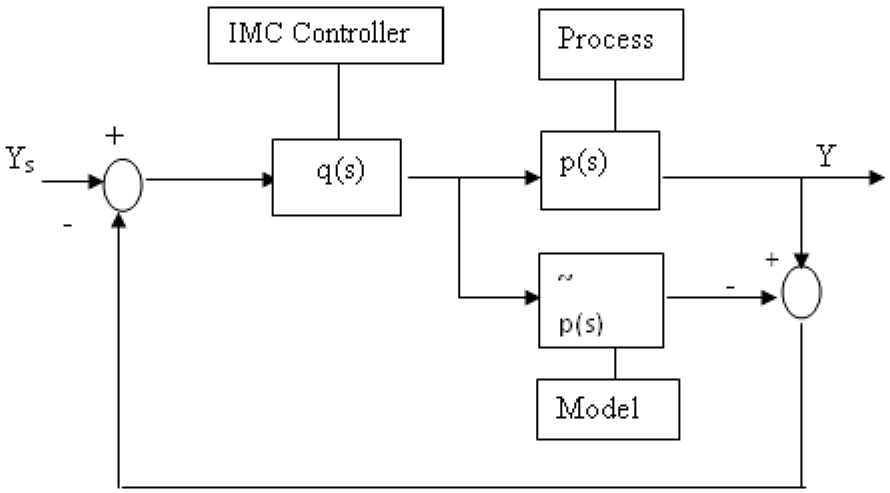

Fig. 2. IMC Structure.

$$p(s) = \frac{k\ell^{-\tau_D s}}{\tau s + 1} \tag{4}$$

$$q(s) = q(s)^{-} f \tag{5}$$

$$q(s)^{-} = \frac{\tau s + 1}{K} \tag{6}$$

$$f = \frac{1}{\lambda s + 1} \tag{7}$$

From the above equation, the only tuning parameter is λ and hence IMC controller is simple.

4.1. IMC Based PI Controller

The IMC structure shown in the Fig. 3 can rearranged as shown in the Fig. 4 after applying block diagram reduction the Fig. 3 is reduced to simple feed back structure as shown in the Fig. 4.

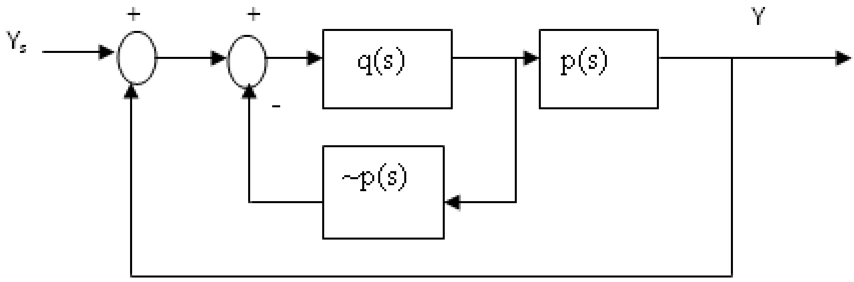

Fig. 3. Basic IMC Structure.

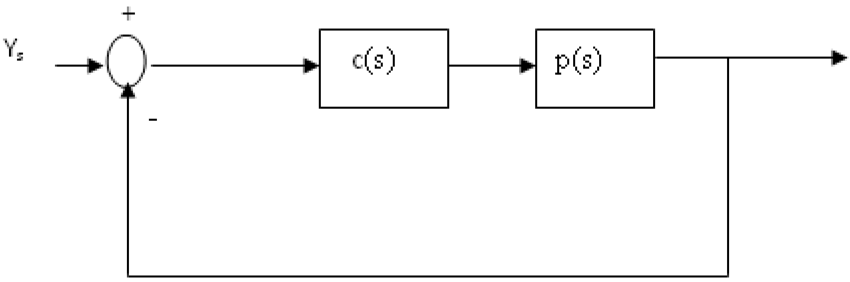

Fig. 4. Modified IMC structure.

The controller function C(s) in the figure is given by

$$c(s) = \frac{q(s)}{1 - q(s)p(s)} \tag{8}$$

$$q(s) = q(s)^{-} f \tag{9}$$

$$p(s)^{-} = \frac{k(1 - \tau_D s)}{(\tau s + 1)} \tag{10}$$

Substituting Eqns. 9&10 in eel 8 and rearranging then in the form of PI controller, the value of K_C and τ_i

$$K_C = \frac{\tau_P}{K_P(\lambda + \tau_D)} \tag{11}$$

$$\tau_i = \tau \tag{12}$$

For fast response and good robustness the tuning parameter is given by equation (13)

$$\lambda = \tau_D \tag{13}$$

The above method is proposed by Skogestad [16] has used the IMC framework to derive rules for model reduction and PI/PID controller tuning. Skogestad's IMC (SIMC in short) tuning rules are analytically derived, are simple, and work well on a wide range of processes. A salient feature is that, because SIMC rules are intended for PI/PID controllers, a first- or second order process model of the process must be obtained. He has proposed a simple procedure based on a "half-rule" to obtain an approximate model of the process. The result is an approximate first- or second-order plus time-delay process model. Once these reduced-order models are obtained, the PI/PID controller gains are computed to adjust the closed-loop response to a first- or second-order model reference response. This procedure gives rise to a set of simple analytical PI/PID tuning rules.

5. Results and Discussion

The designed IMC controller for the process is implemented in the IMC structure and simulated in MATLAB. Their characteristics, based on rise time (tr), settling time (ts) are compared with conventional PI for both set and load changes and shown in Figs. 5 to 11. From Fig. 5 and Fig. 6 the ZN PI controller is significantly more sluggish, because of the low value of the integral gain.

The results for the FOPDT model for the set and load changes using SIMC is given in Fig. 8 and Fig. 9. We find that the PI settings using SIMC yield a very good response in both the set and load changes. The recommended SIMC settings with $\lambda = \tau_D$ gives the fast closed loop response subject to achieving reasonable robustness. One main advantage of SIMC tuning method is detuning is easily done by selecting a large value for lambda to reduce the measurement noise and to make operation smoother.

In Fig. 7 and Fig. 10, when the multiple load changes has been given SIMC gives the lesser overshoot when compares with the PI controller. It can be seen that an IMC method gives good servo control and regulatory control.

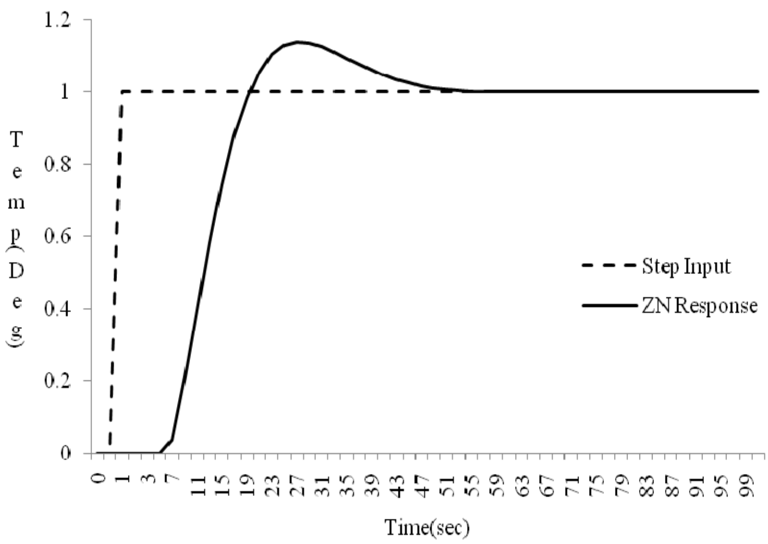

Fig. 5. Servo response of a process for PI controller.

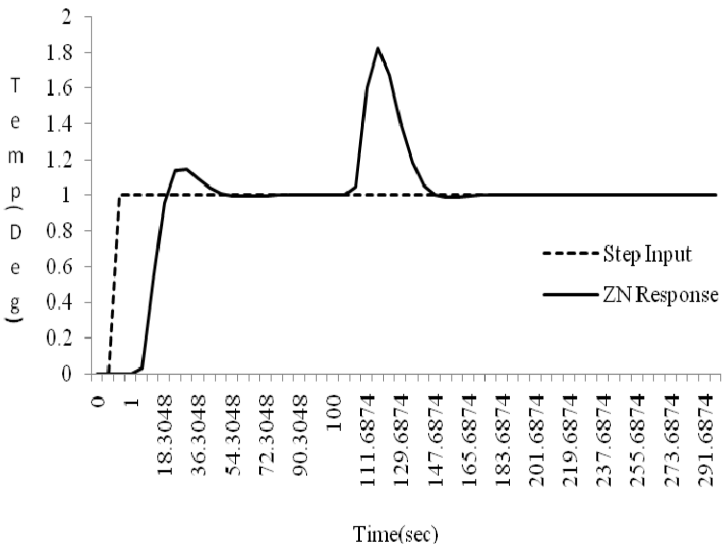

Fig. 6. Load response of a process for PI controller.

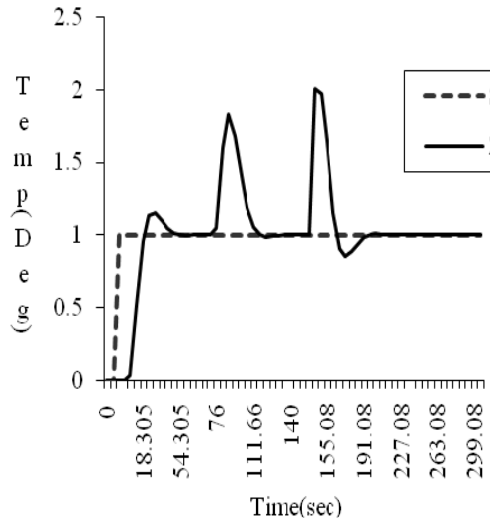

Fig. 7. Multiple Load response of a process for PI controller.

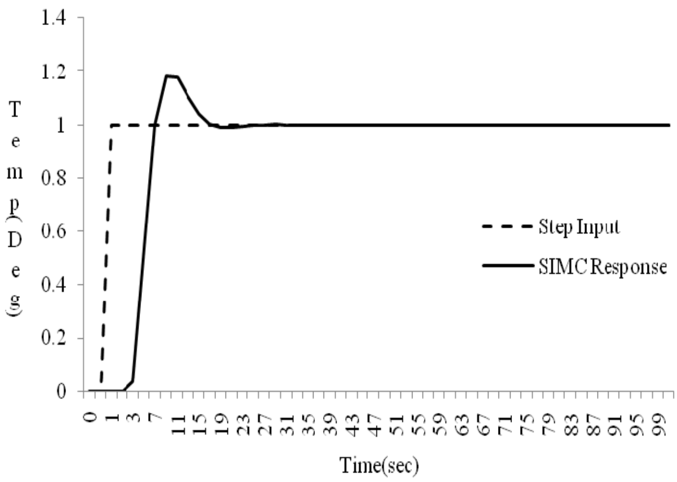

Fig. 8. Servo response of a process for IMC.

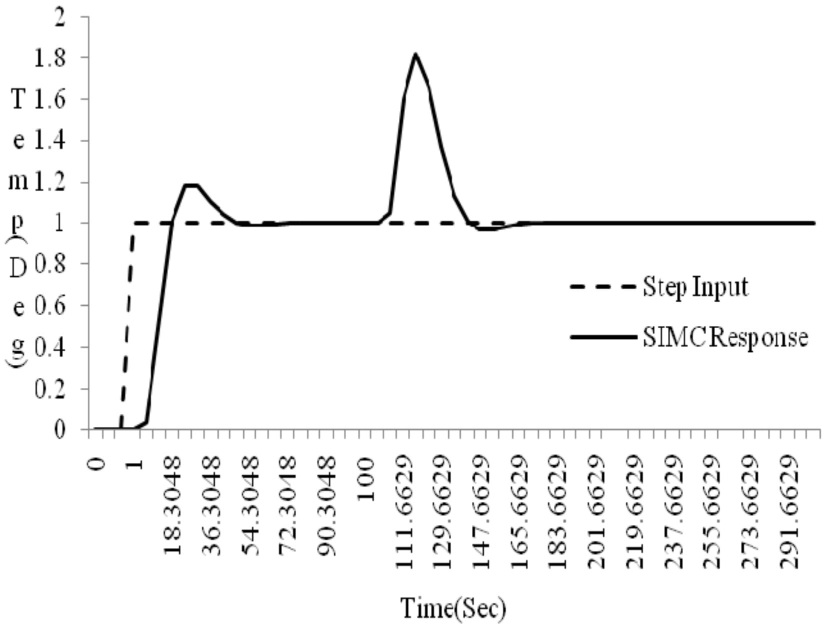

Fig. 9. Load response of a process for IMC.

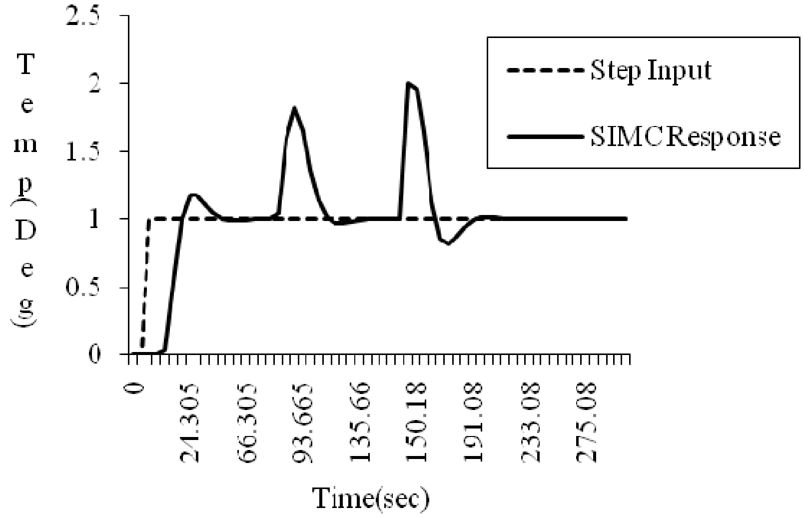

Fig. 10. Multiple Load response of a process for IMC.

The IMC method is based on an assumed process model leads to analytical expressions for the controller settings. The IMC approach has the advantage that it allows model uncertainty and tradeoffs between performance and robustness to be considered for a process system. Fig. 11 illustrates the system performance for both IMC and PI. It is clear that SIMC has the faster rise time and settling time. It is not following the sluggish response as that of a PI controller.

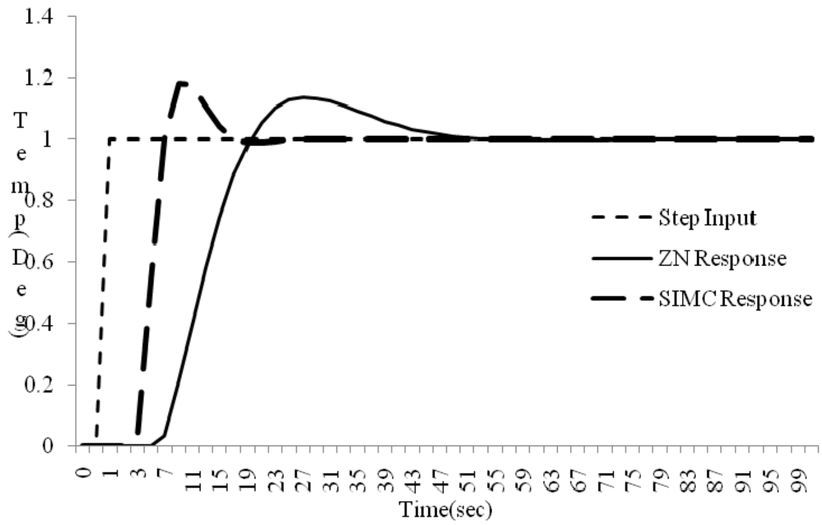

Fig. 11. Comparison of IMC with PI Controller.

The steady state performance comparison of the conventional PI with SIMC is as shown in Table 2. It is observed that the performance indices for SIMC based tuning has been significantly reduced.

Table 2. Performance comparison of IMC controller with Conventional PI controller.

PARAMETER	PI	SIMC
Rise Time t_r (s)	15	13
Settling Time t_s (s)	44.3	25
ISE	9.22	9.07
IAE	14.08	11.88
ITAE	172.21	98.33

6. Conclusions

The controller design is the most important concept for a good control, which is achieved if the response has minimum rise and settling time. IMC has only one tuning parameter per output and hence design of the IMC structure is simple. The reduction in tunable parameter in IMC compared to conventional PI the search for the correct value is simple and faster. The tuning parameter moderates the feedback action to maintain better performance of the controller and manipulated variables in the presence of error as well as noise. The IMC controller designed for process shows minimum rise and settling time .Hence from the above results it is conclude that IMC seems to be a better choice for the heat exchanger process than conventional PI controllers.

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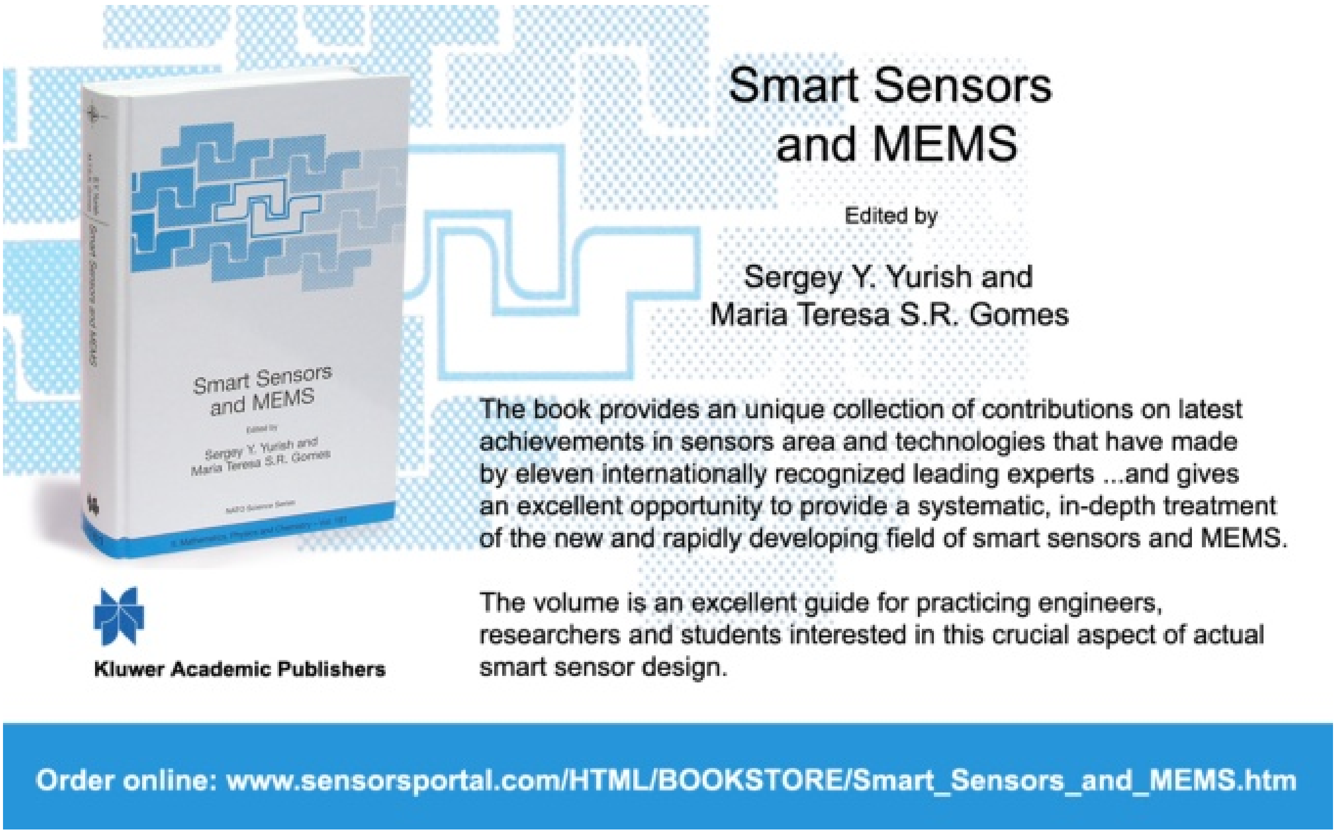

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
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