Internal Model Controller for Temperature Control of Shell and Tube Heat Exchanger System

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Abstract— The purpose of a heat exchanger system is to transfer heat from a hot fluid to a cooler fluid, so temperature control of outlet fluid is of prime importance. To control the temperature of outlet fluid of the exchanger system a conventional PID controller can be used. Due to inherent disadvantages of conventional control techniques, model based control technique is employed and an internal model controller is developed to control the temperature of outlet fluid of the exchanger system. The internal model controller provides a satisfactory performance in both steady state and transient state and results are compared with Variation in temperature without controller. From the simulation results, it is found out that Internal model controller outperforms feedback PID controller.

Key words: Internal Model Controller, PID Controller, Shell and Tube heat exchanger

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. They can operate at high pressures, and their construction facilitates disassembly for periodic maintenance and cleaning. Shell-and-tube heat exchangers find widespread use in refrigeration, power generation, heating and air conditioning, chemical processes, manufacturing, and medical applications. A shell-and-tube heat exchanger is an extension of the double-pipe configuration. Instead of a single pipe within a larger pipe, a shell-and-tube heat exchanger consists of a bundle of pipes or tubes enclosed within a cylindrical shell. 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.

This paper reports a work that considers a shell and tube heat exchanger and builds a single input-single output model of the system with the help of experimental data. 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, the plant is analyzed without any controller which is characterized by very high overshoot and large settling time. Then a PID controller is used to control the parameters. PID controller also exhibits high overshoots which is undesirable. To reduce the overshoot internal model controller is used. In the model based controller the process model is implemented in parallel with the real process. The internal model controller based controller design has gained widespread acceptance because it has only a single tuning parameter namely the closed loop time constant λ. The controller is designed according to a model of the actual process. The internal model controller reduces the overshoot and settling time. In this research paper two type of controller 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 process fluid which is the output of the chemical reactor is stored in the storage tank. The storage tank supplies the fluid to the shell and tube heat exchanger system using a pump and a non returning valve. The heat exchanger heats up the fluid to a desired set point using super heated steam at 180°C supplied from the boiler. 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 research paper. The first assumption is that the inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the heat exchanger. 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 (voltage) 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 (fail-close) valve. The actuator unit takes the controller output in the range of 4-20 mA and converts it in to a standardized pressure signal, i.e in the range of 3-15 psig. The valve actuates according to the controller decisions. Figure 1 shows the basic feedback control scheme implemented in a shell and tube heat exchanger system.

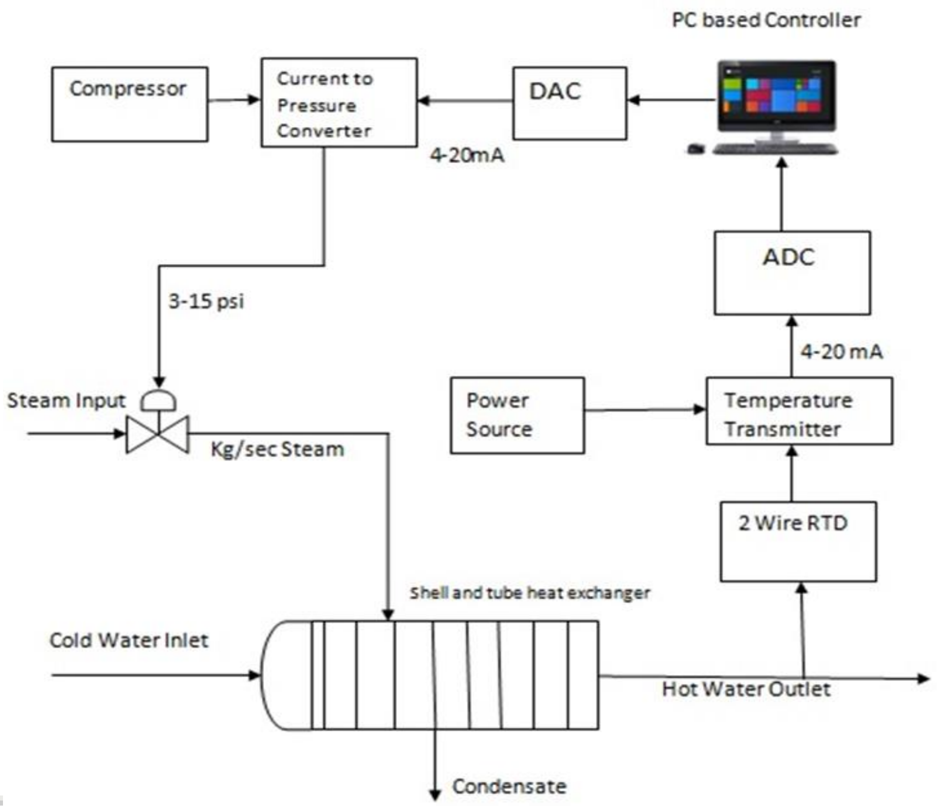

Fig. 1: Shell and tube heat exchanger system control scheme

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 modeled using the available experimental data. The experimental process data is summarized below.

Exchanger response to the steam flow gain 50°C/(kg/sec)
Time constant 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/(kg/sec)

Control valve capacity 1.6 kg/sec for steam
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, the gains are obtained as below.

Transfer function of valve $\frac{50}{30s+1}e^{-s}$

Gain of valve 0.13

Transfer function of valve $\frac{0.13}{3s+1}$

Gain of current to pressure converter 0.75

Transfer function of flow disturbance $\frac{1}{30s+1}$

Transfer function of temperature disturbance $\frac{3}{30s+1}$

Transfer function of thermocouple $\frac{0.16}{10s+1}$

Figure 2 represents the transfer function block diagram of feedback control of shell and tube heat exchanger system.

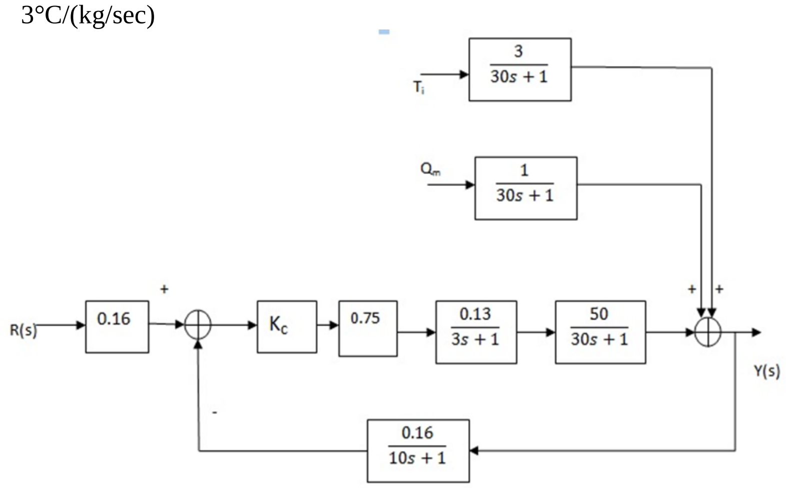

Fig. 2: Feedback control of shell and tube heat exchange system

The characteristic equation l+G(s)H(s) =0 in this case is obtained as below.

$$900s^3+420s^2+43s+0.798K_c+1=0 \quad (1)$$

Routh stability criterion gives Kc as 23.8.

$$\text{Auxiliary equation } 420s^2+0.798K_c+1=0 \quad (2)$$

ω=0.218 and T=28.79

PID controller in continuous time is given as

$$U(t)=K_c\left(e(t) + \frac{1}{\tau}\int_0^t e(t)dt + \tau_d\frac{de(t)}{dt}\right) \quad (3)$$

According to Zeigler-Nichols frequency response tuning criteria

Kp = 0.6Kc

τ_i= 0.57T and

τ_d= 0.125T

IV. 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.

Figure 3 represents block diagram representation of internal model controller.

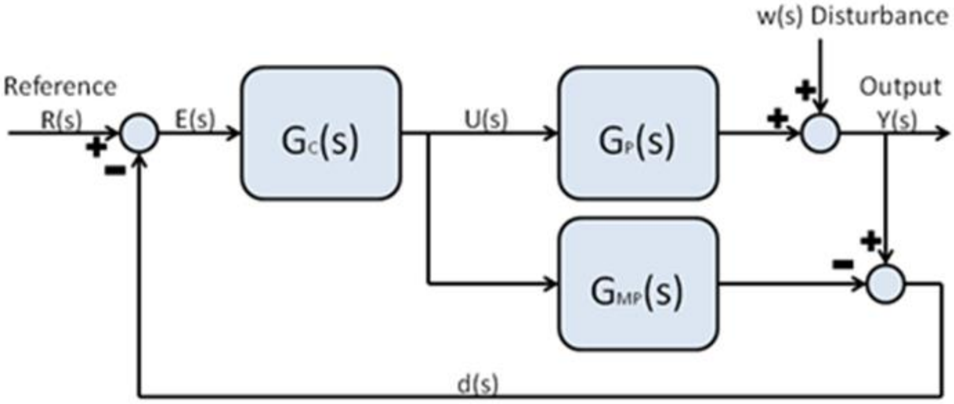

Fig. 3: Internal model controller

V. SIMULATION AND TESTING

The simulations for the different control mechanism discussed above were carried out in Simulink and the simulation results have been obtained. Firstly we calculate response of shell and tube heat exchanger without controller. Then we calculate response of heat exchanger with PID controller and after that we calculate the response of Internal model controller.

A. *Heat Exchanger without Controller:*

Figure 4 represents the simulink modelling of shell and tube heat exchanger system without controller.

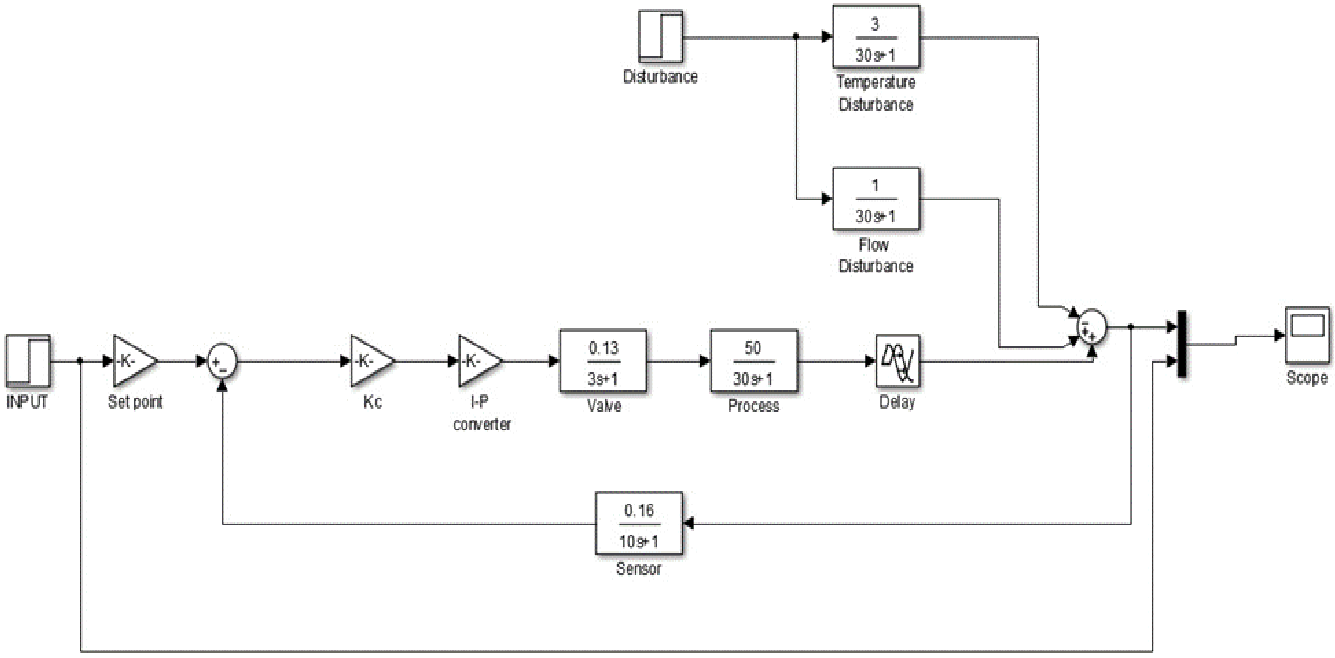

Fig. 4: Simulink model of shell and tube heat exchanger without controller

Figure 5 shows the step response of shell and tube heat exchanger without controller.

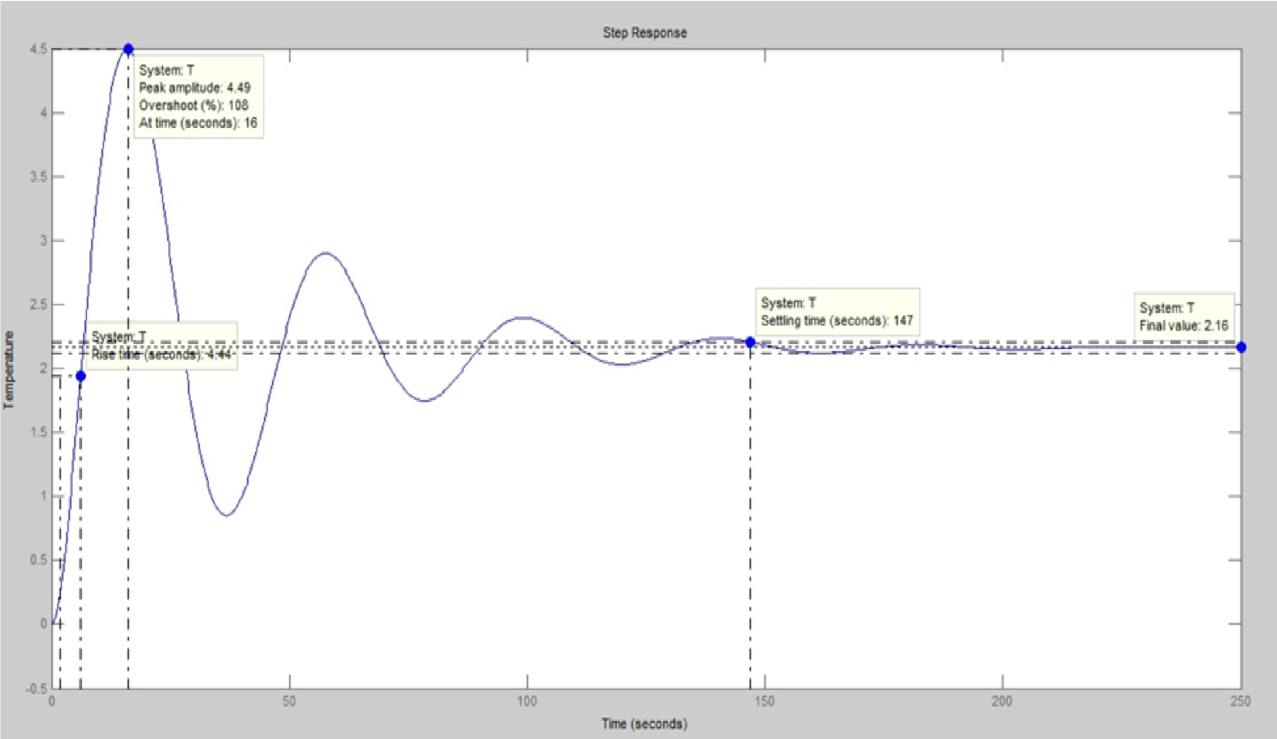

Fig. 5: Unit step response of shell and tube heat exchanger without controller

B. *Heat Exchanger with PID Controller:*

Figure 6 represents the simulink modelling of shell and tube heat exchanger system with PID controller.

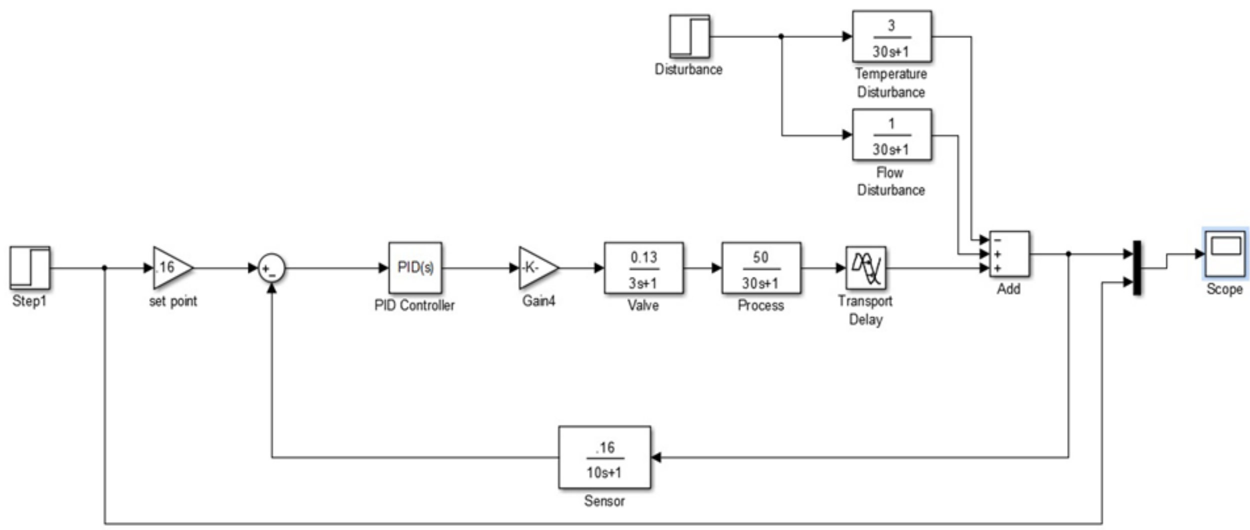

Fig. 6: Simulink model of shell and tube heat exchanger with PID controller

Figure 7 shows the step response of shell and tube heat exchanger with PID controller. The PID controller will increase the %overshoot but decreases the settling time and steady state error will also decrease.

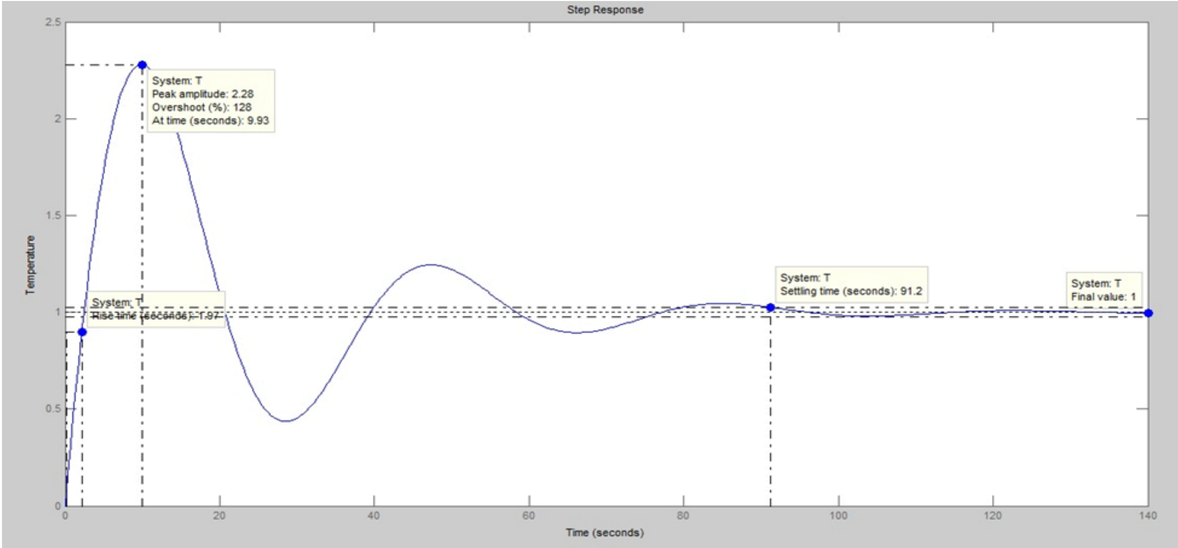

Fig. 7: Unit step response of shell and tube heat exchanger with PID controller

C. Heat Exchanger with Internal Model Controller

Figure 8 represents the simulink modelling of shell and tube heat exchanger system with internal model controller.

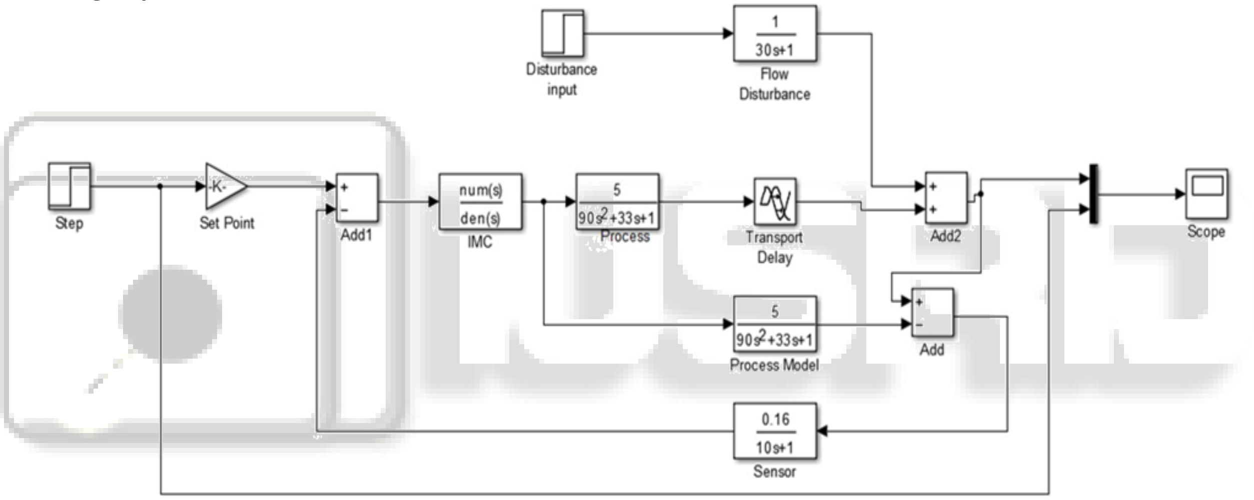

Fig. 8: Simulink model of shell and tube heat exchanger with internal model controller

Figure 9 shows the step response of shell and tube heat exchanger with Internal model controller. The Internal model controller will decrease the %overshoot, settling time and steady state error as compared to heat exchanger without controller.

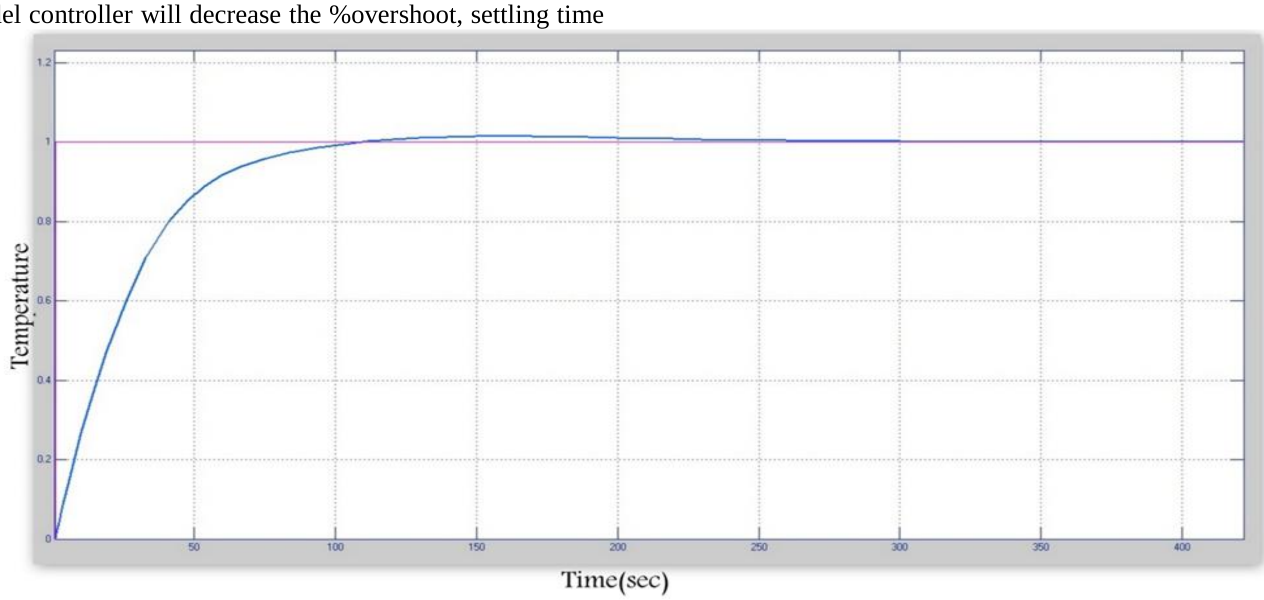

Fig. 9: Unit step response of shell and tube heat exchanger with internal model controller

VI. COMPARATIVE STUDY OF PARAMETERS

	Overshoot (%)	Settling Time (sec)	Steady state Value
Without controller	108	147	2.16
With PID Controller	128	91.2	1.00
With Internal model controller	15	78	1.00

Table 1: Comparison of Different Parameters

VII. CONCLUSION

This paper takes a case study of shell and tube heat exchanger system and evaluates different methods to control the outlet fluid temperature. Two different kind of controllers are designed to control the outlet temperature of fluid and the performances of these controllers are evaluated in terms of time domain analysis of overshoot and settling time and steady state value This paper takes the process model to be the same as the process, which is practically impossible to achieve. So as a further work we can implement direct model and inverse model based controller and apply system identification as well as neural network concepts for estimation of process model.

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