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PERFORMANCE ANALYSIS OF VARIOUS CONTROLLER FOR A HEAT EXCHANGER SYSTEM

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ABSTRACT

This paper analyzes the performance of different controllers such as Proportional controller, Proportional plus derivative controller and Proportional plus derivative plus integral controller(PID) to regulate the temperature of outlet fluid of a shell and tube heat exchanger to a certain reference value. The transient performance and the error criteria of the controllers are analyzed and the best controller is found out. From the simulation results, it is found out that the PID controller outperforms Proportional and proportional plus derivative controller.

***Keywords**: PID, Proportional controller, Proportional plus derivative controller, Heat Exchanger system.*

I. INTRODUCTION

Design of controller for any regulatory or servo problem is one of the challenging tasks due to many aspects. To design a controller, an accurate mathematical model is required which can be obtained either from first principle model or from black box system identification experiment. A controller has two distinct objectives such as set-point tracking and load disturbance rejection. Set-point tracking is a major issue in servo control whereas the main focus area of regulatory control is load disturbance rejection and to maintain steady state conditions. Apart from the mathematical model of the process the system designer has to consider various other aspects like process uncertainty, measurement noise, and robustness of system while developing a controller. Proportional-Integral-Derivative (PID) controller, the most commonly used controller finds wide spread applications in various areas of automatic control. Though there are several high end controllers superior to existing PID and its variants, the simplicity and proven track record of PID controller makes it an obvious choice for most of the control problems. While developing a PID type controller (PI or PD) different practical consideration has to taken care off. These practical concerns are filtering of measurement noise and tradeoff between robustness and performance. Tuning of PID controller is a wide area of research with many tuning rules where the main objective is to formulate such a tuning rule which can be characterized from the mathematical model of the system. So there are different set of conditions and different set of tuning rules for each and every process dynamics.

Apart from introductory section, this paper has four different sections. In section 2, system configuration is introduced and mathematical model of the system is obtained. In section 3, different control configurations is discussed. Section 4, provides simulation results for different control techniques and the best controller design technique is identified from the transient response performance and error criteria. Section 5 concludes the paper.

II. HEAT EXCHANGER SYSTEM

Heat Exchanger transfer heat between two fluids without mixing them up. The dynamics of heat exchanger depends on many factors like temperature difference, heat transfer area, flow rate of fluids, flow patterns. Heat exchanger finds wide spread applications in different industries such as petroleum, food, petrochemical, power generation, nuclear, space craft etc. The basic principle of heat exchanger is shown in Fig. 1.

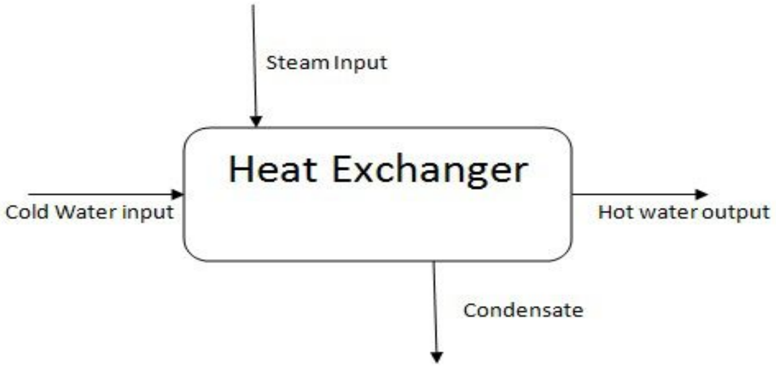

Figure 1: Principle of heat exchanger

Shell and tube heat exchanger probably is the most common type of heat exchangers applicable for wide range of operating temperature and pressure. It has larger ratio of heat transfer surface to volume than double-pipe heat exchangers, and it is easy to manufacture in a large variety of size and configuration. Shell and tube heat exchanger can operate at high pressures, and its construction facilitates disassembly for periodic maintenance and cleaning. 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.

2.1 System Description

The schematic diagram of temperature control of a shell and tub heat exchanger is shown in Fig. 2.

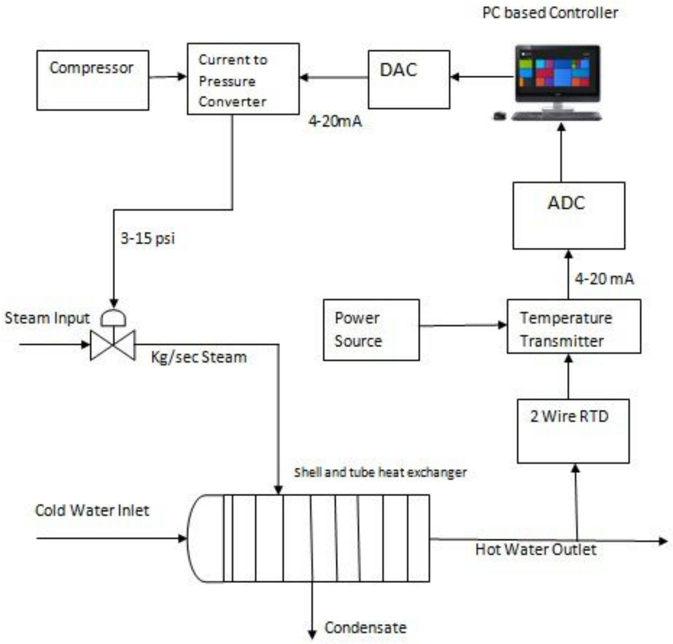

Figure 2: Schematic diagram of temperature control of heat exchanger

Input cold water is supplied from the overheat tank to the shell side of the heat exchanger. Steam is supplied to the tube side of the heat exchanger. A 2-wire RTD is used to measure the output temperature of the heat exchanger and is connected to the transmitter. The 2-wire RTD transmitter produces a standard 4-20 mA output which is proportional to the temperature. The transmitter helps to reduce the noise in measurement. A separate power source is supplied to the transmitter unit. The data from the transmitter is updated in the PC based controller using a data acquisition (DAQ) device. The PC based controller processes the error signal and computes the appropriate control signal. The controller unit sends the corresponding control signal to current to pressure converter via another DAQ device. The current to pressure converter converts the current output of PC based controller to appropriate pressure signal so that the steam valve can be actuated in a proper manner. The experimental data available for the heat exchanger system is summarized below.

Exchanger response to steam flow gain is 50°C/kgsec^{-1}, time constant is 30 sec, Exchanger response to variation of process fluid flow gain 1°C/kgsec^{-1}, Exchanger response to variation of process temperature gain 3°C/°C, capacity of control valve 1.6kg/sec, time constant for control valve is 3 sec, time constant for sensor is 10 sec.

From the experimental data linearized mathematical model of heat exchanger is developed.

2.2 Mathematical Model

To design a controller, a proper mathematical model of the process has to be determined. Most of the industrial system are non-linear in nature and can be approximated as first order plus time delay (FOPTD) or second order plus time delay (SOPTD) models.

Transfer function model of heat exchanger system is $G_p(s) =$

Transfer function model of valve is $G_v(s) =$

Transfer function model of sensor is $H(s) =$

Transfer function model of flow disturbance is $G_d(s) =$

Transfer function model of temperature disturbance is $G_t(s) =$

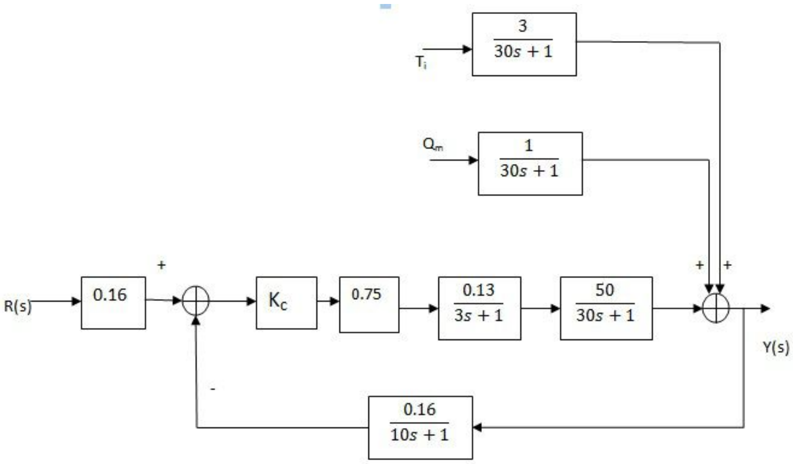

Figure 3: Feedback control of heat exchanger system

III. CONTROL ALGORITHMS

To control the outlet temperature of heat exchanger system closed loop control is required which can be achieved by a controller. The control algorithm considered to achieve the desired control objective are Proportional controller, Proportional plus derivative controller and Proportional-Integral-Derivative (PID) controller.

3.1 Proportional controller

The block diagram of a closed loop feedback control with proportional controller is shown in Fig. 4.

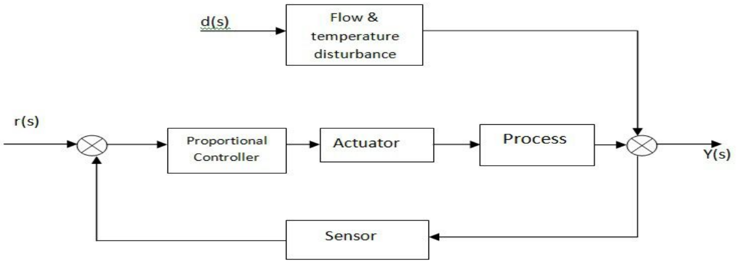

Figure 4: Block diagram of Proportional controller

According to Zeigler-Nichols frequency response tuning criteria

$K_p = 0.6K_c$
And $K_c = 23.8$
So $K_p = 14.28$

With application of proportional controller, damping ratio will decrease, as a result percentage overshoot will increase. Also steady state error will decrease by factor K_p.

3.2 Proportional- Derivative Controller

The block diagram of a closed loop feedback control with proportional plus derivative controller is shown in Fig. 5.

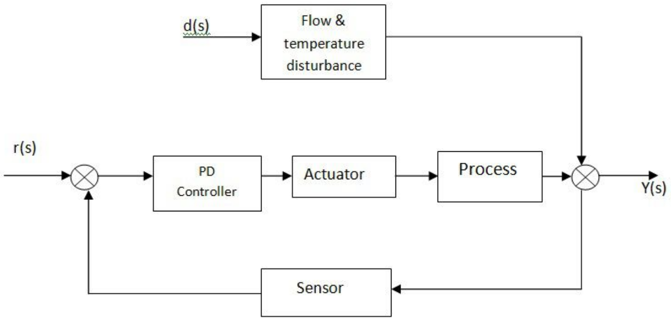

Figure 5: Block diagram of Proportional –Derivative controller

According to Zeigler-Nichols frequency response tuning criteria

$K_p = 0.6K_c$
$_d = 0.125T$ and $T = 28.79$
So $K_p = 14.28$ and $K_d = 52.629$

With application of proportional- derivative controller, damping ratio will increase, as a result percentage overshoot will decrease. Also rise time and settling time will decrease. And therefore stability will increase.

3.3 Proportional- Derivative – Integral Controller

The block diagram of a closed loop feedback control with proportional plus derivative plus integral controller is shown in Fig. 6.

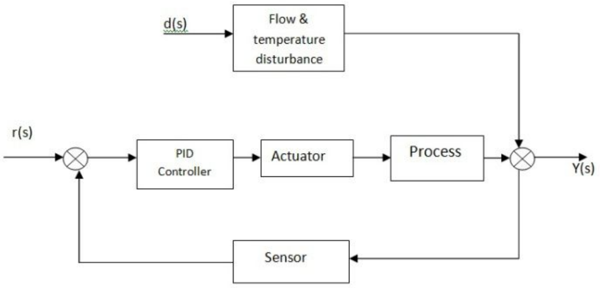

Figure 6: Block diagram of Proportional –Derivative-Integral controller

According to Zeigler-Nichols frequency response tuning criteria

$K_p = 0.6K_c$
$_i = 0.57T$ and
$_d = 0.125T$
So $K_p = 14.28$, $K_d = 52.629$ and $K_i = 1.020$

P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability.

IV. 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 with proportional controller. Then we calculate response of heat exchanger with PD controller and after that we calculate the response of PID controller.

4.1 With Proportional Controller

Figure 7 represents the simulink modelling of shell and tube heat exchanger system with proportional controller.

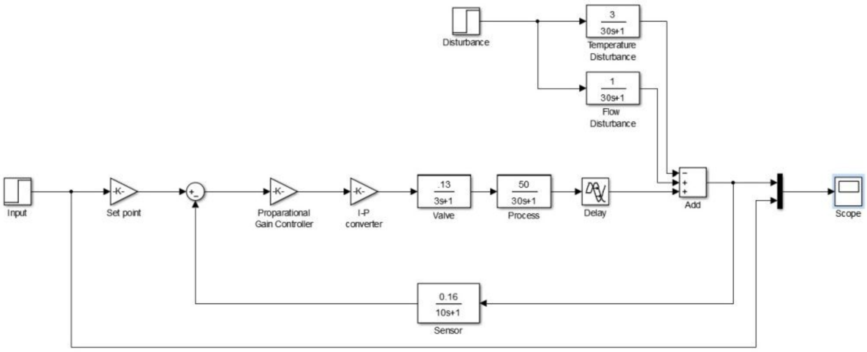

Figure 7: Simulink model of shell and tube heat exchanger with proportional controller

Figure 8 shows the step response of shell and tube heat exchanger with proportional controller.

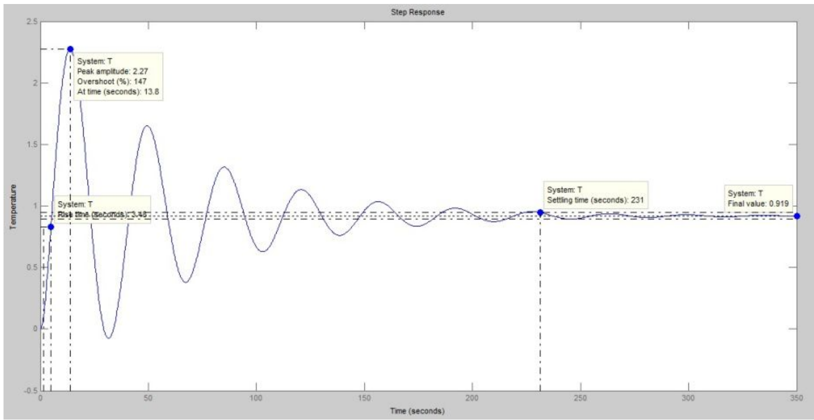

Figure 8: Unit step response of shell and tube heat exchanger with proportional controller

4.2 With Proportional –Derivative controller

Figure 9 represents the simulink modelling of shell and tube heat exchanger system with proportional - derivative controller.

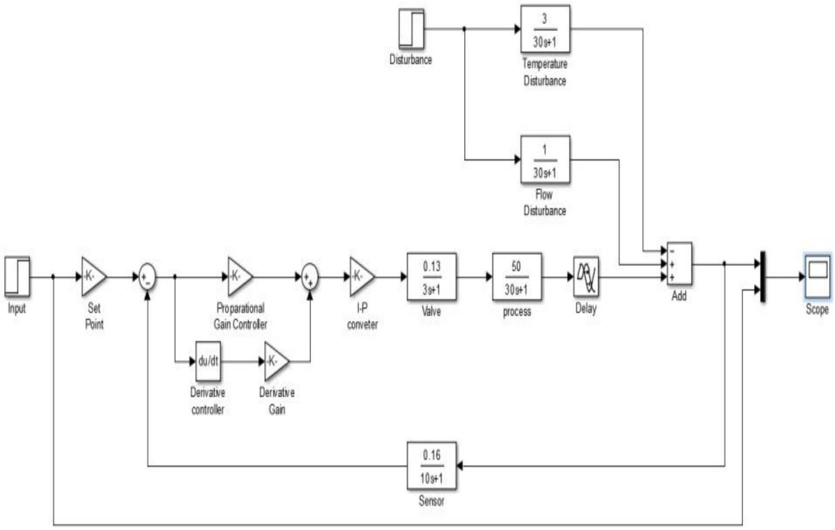

Figure 9: Simulink model of shell and tube heat exchanger with proportional- derivative controller

Figure 10 shows the step response of shell and tube heat exchanger with proportional- derivative controller.

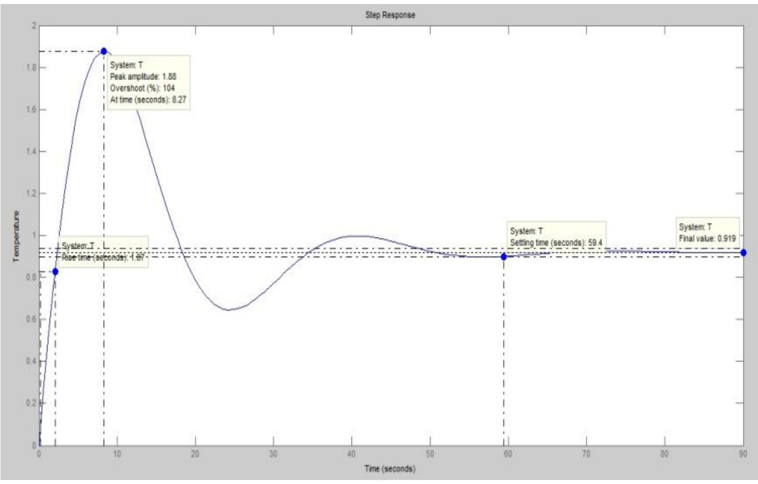

Figure 10: Unit step response of shell and tube heat exchanger with proportional- derivative controller

4.3 With PID Controller

Figure 11 represents the simulink modelling of shell and tube heat exchanger system with PID controller.

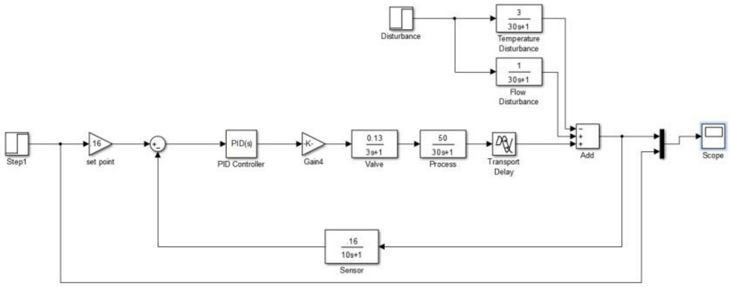

Figure 11: Simulink model of shell and tube heat exchanger with PID controller.

Figure 12 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.

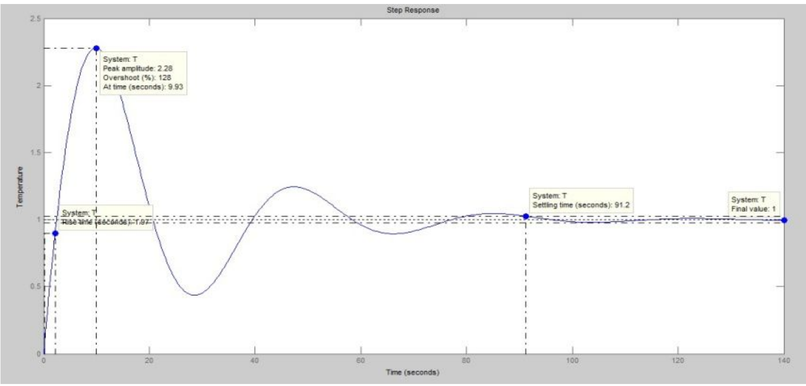

Figure 12: Unit step response of shell and tube heat exchanger with PID controller

COMPERATIVE STUDY OF PARAMERTERS

The transient response (peak overshoot and settling time) in unit step response of all the controllers (Proportional , Proportional- derivative, and PID controller) is summarized in Table 1.

	Overshoot (%)	Settling time (sec)	Final Value
Proportional controller	147	231	0.919
Proportional Derivative Controller	104	59.4	0.919
Proportional Integral Derivative Controller	128	91.2	1

TABLE 1: Comparison of different parameters

V. CONCLUSION

This paper implements different controller (Proportional, Proportional- derivative, and PID controller) to control the outlet temperature of a shell and tube heat exchanger system. Mathematical model of the heat exchanger is developed using experimental data and the process model is used to develop the respective controller. The performance of different controllers are evaluated using transient characteristics . From the simulation results, it is found that the PID control has a superior performance than P and PD controller. The Proportional controller shows a higher degree of overshoot and settling time whereas the PID control negates the overshoot and has a manageable settling time.

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