

---

## Controller Design for Temperature Control of Heat Exchanger System: Simulation Studies

Miss. Mayuri H. More<sup>1</sup>, Dr. M.G. Poddar<sup>2</sup>

<sup>1</sup>(Department of Post Graduation (Control System Engineering), M. B. E. Society's College of Engineering Ambajogai, India)

<sup>2</sup>(Department of Post Graduation (Control System Engineering), M. B. E. Society's College of Engineering Ambajogai, India)

---

**Abstract :** Heat exchanger system is mostly used in chemical plants due to its property to sustain temperature and pressure. The main aim of a heat exchanger system is to heat transfer from a hot fluid to a cooler fluid. In this Temperature control of heat exchanger system we design different controllers such as Feedback, Feed forward and Feedback plus Feed forward controllers. Analyzing the performance of those controllers and regulate the temperature of outlet fluid of a shell and tube heat exchanger to a certain reference value. The transient performances of these controllers are analyzed and the best controller is found out. From the simulation results, it is found out that the feedback plus feed-forward controller has a superior performance than feedback controller.

---

**Keywords :** Shell and tube heat exchanger system, Feed-forward controller, Feedback controller, PI controller and Feedback plus Feed forward controller.

---

### 1. Introduction

Heat exchanger is mostly used in chemical processes to transfer heat from a hot fluid through a solid wall to a cooler fluid. Shell and tube heat exchangers are commonly used in type temperatures and pressures. A shell and tube heat exchanger is a double-pipe configuration. In shell and tube heat exchanger one fluid flows through the tubes and another fluid flows within the space between the tubes and the shell [1]. The PI controller is implemented and, compares the output with the set point and then it gives a necessary command to the final control element via the actuator unit. We have to design a controller for temperature control of a heat exchanger system by calculating the transfer functions of Feedback, Feed-forward, and Feedback plus Feed-forward controller.

Apart from the introductory section, in this paper have four different sections. In section I, the heat exchanger system and the controllers which are used in this paper are introduced. In section II, the basic heat exchanger and mathematical modeling of the system are designed in Materials and Methods. In section III, results and

discussion provide simulation results for different control techniques and the best controller design technique is identified from the transient response performance and error criteria. In section IV, How we can conclude the best controller.

## 2. Materials and Methods

In this section develop the mathematical model of the system by calculating the transfer function of the different controllers. By developing control algorithms of different controllers like feed-forward, feedback PI controller and the combination of feedback plus feed-forward controller. First, discuss a basic heat exchanger system. Developing a mathematical model of the heat exchanger system and calculate the first order plus dead time model (FOPDT) of the system.

### 2.1 System Description

The thermocouple is used to measure the temperature of the outgoing fluid and the output of the thermocouple (voltage) is sent to the transmitter unit, which finally converts the thermocouple output into a standardized signal in the range of 4-20 MA. The controller implements the control algorithm, compares the output with the set point and then Different assumptions have been considered in this paper. The first assumption is that the inflow rate and the outflow rate of fluid are the same so that the fluid level is maintained constant in the heat exchanger. The actuator unit is used to current to pressure converter and the final control unit is an air to open valve. (fail-close)

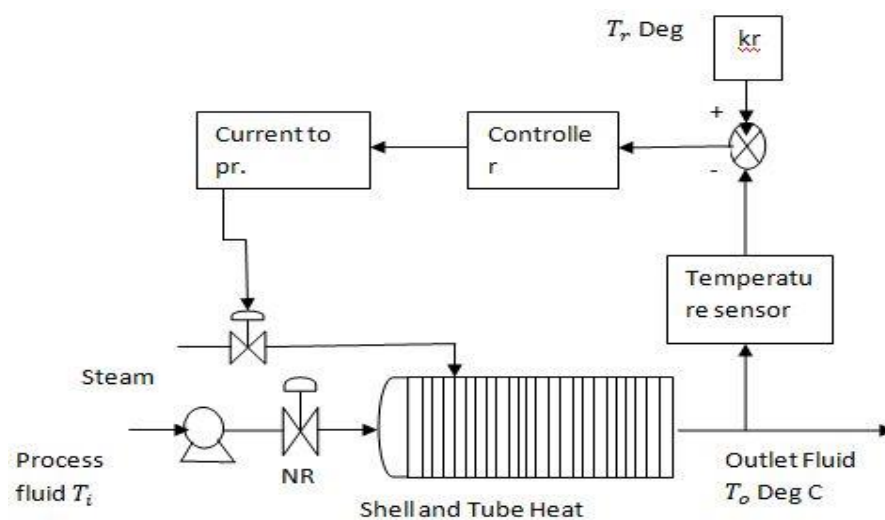


Fig. 1 Heat Exchanger System Control Scheme

## 2.2 Mathematical Modeling

### 2.2.1 Heat Exchanger Process

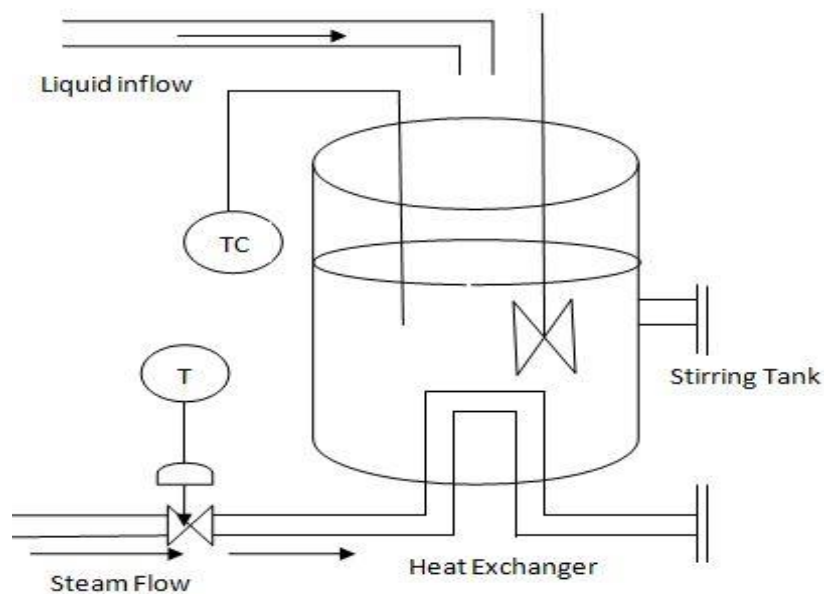


Fig 2 Stirring Reactor with Heat Exchanger

A chemical reactor called "stirring tank" is given below. The liquid inflow delivers liquid to be mixed in the tank. The tank liquid maintained at a constant temperature by varying the amount of steam supplied to the heat exchanger (bottom pipe) via its control valve. Variations in the temperature of the inlet flow are the main source of disturbances in this process [10].

### 2.3 FOPDT (first order plus dead time)

To derive a first-order-plus-dead-time model of the heat exchanger system, inject a step disturbance in valve voltage  $V$  and record the effect on the tank temperature  $T$  over time. The measured response in normalized units is shown below [11]:

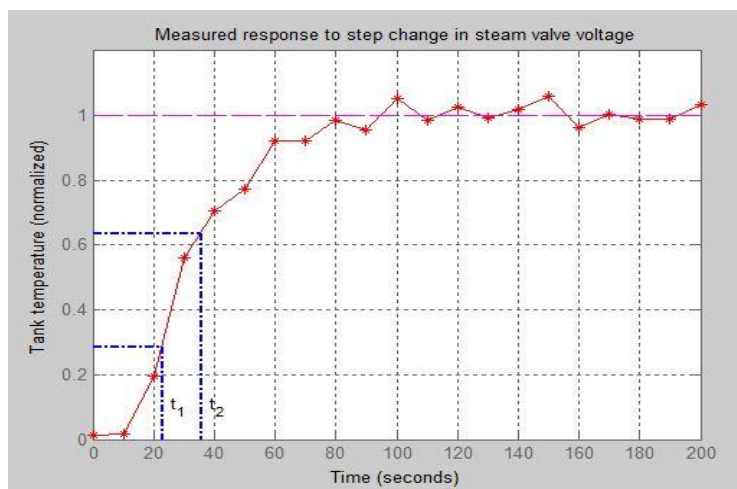


Fig. 3 Measured Responses to Step Change In Steam Valve Voltage

The values  $t_1$  and  $t_2$  are the times where the response attains 28.3% and 63.2% of its final value.

Using these values to estimate the time constant  $\tau$  and dead time  $\theta$  for the heat exchanger:

$$t_1 = 21.8 ; t_2 = 36.0$$

$$\tau = 3/2 * (t_2 - t_1)$$

$$\theta = t_2 - \tau$$

$$\tau = 21.3000$$

$$\theta = 14.7000$$

Verify these calculations by comparing the first-order-plus-dead-time response with the measured response:

$$s = tf('s') ;$$

$$G_p = \exp(-\theta * s) / (1 + \tau * s)$$

$$G_p = \exp(-14.7 * s) * \frac{1}{21.3s + 1}$$

(1)

A block diagram representation of the open-loop process is given below.

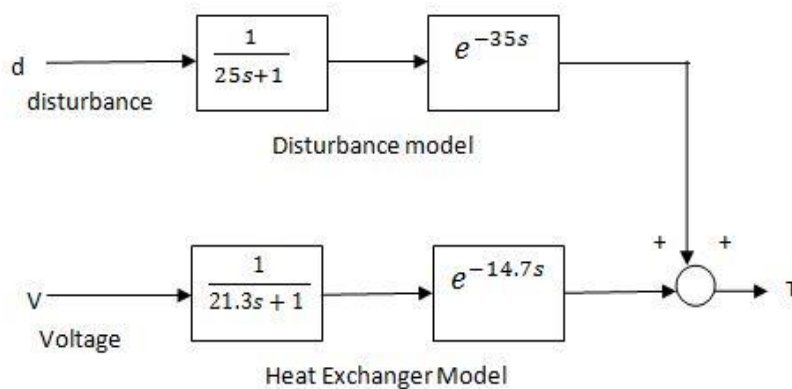


Fig. 4 Open-Loop Process

### 3. Control Algorithms

#### 3.1 PI Controller Action Mode

As the name indicates PI controller is combination of proportional controller and integration controller. The output of this control action mode is proportional to combination of the P & I control action.

Mathematically output of this mode is given by:

$$P = K_p e(t) + K_p K_I \int_0^t e(t) dt + P_I(0) \quad (2)$$

In this control action mode the proportional mode provides one-to-one correspondence and integral mode eliminates the inherent offset.

### 4. Feed-forward control

The feed forward controller F is used to measure the inflow temperature to adjust the steam valve opening (voltage V).

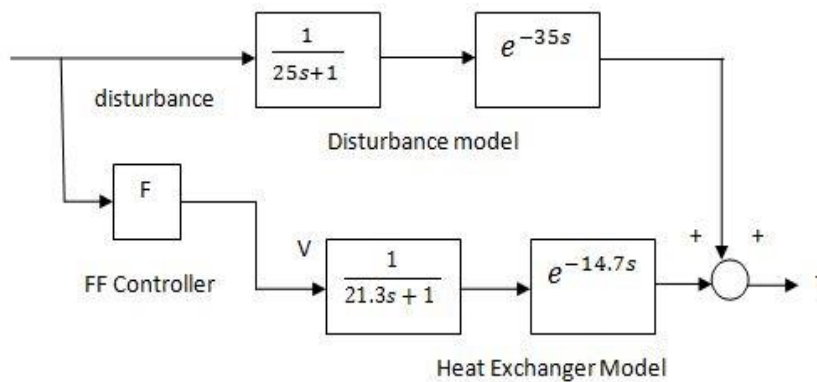


Fig. 5 Feed forward Control

Calculate the overall transfer from temperature disturbance d to tank temperature T is

$$T = (G_p F + G_d) d \quad (3)$$

Disturbance rejection requires

$$G_p F + G_d = 0 \rightarrow F = -\frac{G_d}{G_p} = -\frac{21.3s+1}{25s+1} e^{-20.3s} \tag{4}$$

### 5. Feedback Control

The transfer function

$$G_p(s) = \frac{e^{-14.7s}}{21.3s+1} \tag{5}$$

Models how a change in the voltage V, affects the tank temperature T, while the transfer function

$$G_d(s) = \frac{e^{-35s}}{25s+1} \tag{6}$$

To regulate the tank temperature T around a given set point T<sub>sp</sub>, we can use the following feedback architecture to control the valve opening (voltage V).

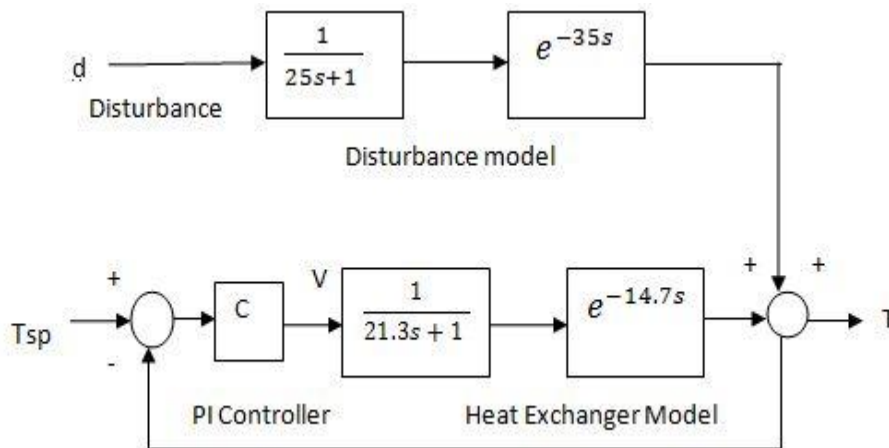


Fig. 6 Feedback Control

In this configuration, the proportional-integral (PI) controller

$$C(s) = K_c \left( 1 + \frac{1}{\tau_c s} \right) \tag{7}$$

Calculates the valve voltage  $V$  based on the gap  $T_{sp}-T$  between the desired and measured temperatures. By using the ITAE formulas to pick adequate values for the controller parameters:

$$K_c = 0.859 \left(\frac{\theta}{\tau}\right)^{-0.977}, \tau_c = 0.859 \left(\frac{\theta}{\tau}\right)^{-0.977} \tag{8}$$

$$K_c = 0.859 * (\theta/\tau)^{(-0.977)}$$

$$\tau_{au_c} = (\tau/0.674) * (\theta/\tau)^{0.680}$$

$$C = K_c * (1 + 1/(\tau_{au_c} * s)) \tag{9}$$

To see how the ITAE controller performs, close the feedback loop and simulate the response to a set point change:

$$K_c = 1.2341$$

$$\tau_{au_c} = 24.5582$$

### 6. Combined Feedback Plus Feed-forward Control

Feedback control is good for set point tracking in general, while feed-forward control can help with rejection of measured disturbances. Look at the benefits of combining both schemes. The corresponding control architecture is shown below:

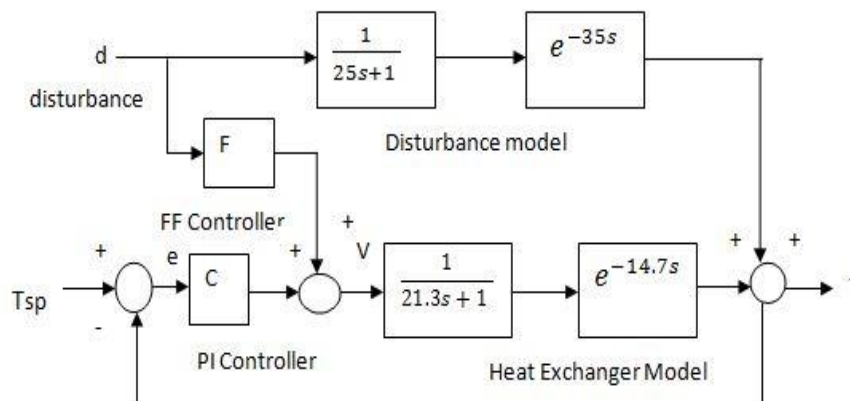


Fig. 7 Feed-forward Feedback Contro



## 7. Results and Discussion

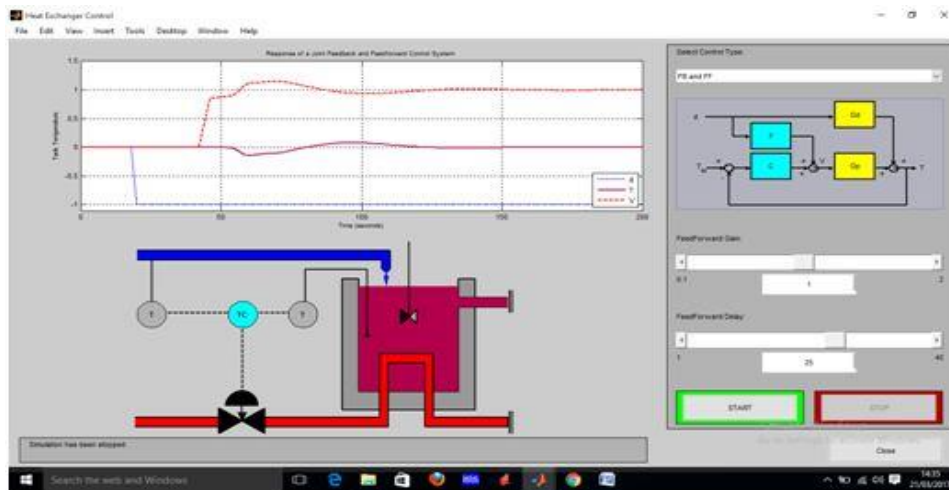


Fig. 8 Feedback plus Feed forward System

In this feedback plus Feed forward system, voltage  $v$  is increases and we get the desired response of the system. It means voltage  $V$  is achieved in less time period. In above fig 5.4 valve is open and steam is flowing into the tank, we can observe that the steam is red in color and tank liquid is heated. As we know the blue liquid is changed in pink. Because of the feedback plus Feed forward system we can achieve the desired output.

| Controller                 | Overshoot | Settling Time |
|----------------------------|-----------|---------------|
| Feed-forward               | 0%        | 97.8 sec      |
| Feedback                   | 15.87%    | 105.5 sec     |
| Feedback plus Feed-forward | 0.33%     | 85.6sec       |

Table 1: Results for transient response of controller

| Controller                 | IAE  | ISE   | ITAE  | ITSE  |
|----------------------------|------|-------|-------|-------|
| Feedback PI                | 2.41 | 0.790 | 1.234 | 28.83 |
| Feedback plus Feed-forward | 1.41 | 0.54  | 0.869 | 24.73 |

Table 2: Results for error indices of controller

## 8. Conclusion

This paper implements a different controller (Feedback, Feed-forward, and Feedback plus Feed-forward controller) to control the outlet temperature of a shell and tube heat exchanger system. The mathematical model of the heat exchanger is developed using experimental data and the process model is used to develop a respective controller. The performances of different controllers are evaluated using transient characteristics and error indices. From the simulation results, it is found that the feedback plus feed-forward has a superior performance than feedback controller. The feedback controller implemented using classical PI controller shows a higher degree of overshoot and settling time whereas the feedback plus feed-forward control negates the overshoot and has a manageable settling time.

## References

- [1] Anton Sodja et.al, "Some Aspects of Modeling of Tube-and-Shell Heat-Exchangers," in *Proc of 7th Modelica Corif-, Italy*, pp. 716-721, Sep 2009.
- [2] L. Ljung, *System identification*. (Springer, 1998).
- [3] V. R. Segovia, T. Hagglund, and K. Aström, "Measurement noise filtering for pid controllers," *Journal of Process Control*, vol. 24, no. 4, pp. 299–313, 2014.
- [4] O. Garpinger, T. Hagglund, and K. J. Aström, "Performance and robustness trade-offs in pid control," *Journal of Process Control*, 2014.



- [5] K. H. Ang, G. Chong, and Y. Li, “*Pid control system analysis, design, and technology*,” *IEEE Transactions on Control Systems Technology*, vol. 13, no. 4, pp. 559–576, 2005.
- [6] W. Tan, J. Liu, T. Chen, and H. J. Marquez, “*Comparison of some well-known pid tuning formulas*,” *Computers & chemical engineering*, vol. 30, no. 9, pp. 1416–1423, 2006.
- [7] B. W. Bequette, *Process control: modeling, design, and simulation* (Prentice Hall Professional, 2003).
- [8] D. Seborg, T. F. Edgar, and D. Mellichamp, *Process dynamics & control* ( John Wiley & Sons, 2006).