Modeling and Simulation of Heat Exchanger Used in Soda Recovery

Chhaya Sharma, Sanjeev Gupta, Vipin Kumar

Abstract- Plant automation system (technical as well as non-technical ones) can't be designed and made operational without using methods of model building and simulation of the system to be automated. In this paper model equations for closed loop temperature control of heat exchanger used in soda recovery section of Star Paper Mills Ltd., Saharanpur (U.P), India has been developed and mathematically simulated on the basis of available information and knowledge. The mathematical model for transfer function of each elements of control loop developed. Software developed for overall transfer function and simulated using MATLAB. The performance analysis of module is examined with PID controller by varying the controller parameters and set-points. The rise time (t_r), peak time (t_p), settling time (t_s) is calculated at set point 110, 115 & 120.

Key Words: Transfer function, Heat Exchanger, Temperature Loop

I. INTRODUCTION

No plant automation system (technical as well as non-technical ones) can be designed and made operational without using methods of model building and simulation of the system to be automated [1,6]**.** Depending on nature of plant and process certain basic knowledge of the subject (viz. physical sciences, engineering etc.) and prior information about the system is needed for modeling purpose. Rapid development of computer based control in the process industry [4, 5] has increased the importance of modeling and simulation of process [1-3]. Based on available information and knowledge, the model equations for heat exchanger used in soda recovery section of Star Paper Mill, Saharanpur, have been mathematically simulated. The transfer function of control elements like sensor, controller, actuator and heat exchanger used in temperature control loop have been mathematically simulated**.** The Process fluid is heated by condensing steam in the heat exchanger. It is assumed that, the process fluid at temperature T(L,t) is heated upto a certain desired outlet temperature θ(t). The energy gained by the process fluid is provided by the latent heat of steam. In the process there are many variables that can change, causing the outlet temperature θ(t) to deviate from its desired value. In such a situation some action must be taken to prevent deviation. The main objective is to maintain the process fluid temperature at the desired value by adjusting the control valve located in the steam line. The proposed model for temperature control loop of heat exchanger is shown in fig.1 and 2. The temperature is measured by a sensor (S) and the output signal goes to controller where it is compared with set point value. Actuating signal from the controller enters the current to pneumatic (I/P) converter which produces a pneumatic signal (3 – 15 psig) to regulate control valve (V) opening thereby regulating the steam flow. This flow enters the heat exchanger and along with other process inputs, produces an output temperature θ(t).

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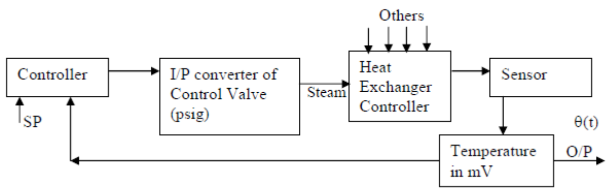

Fig. 1: Block diagram of temperature control loop

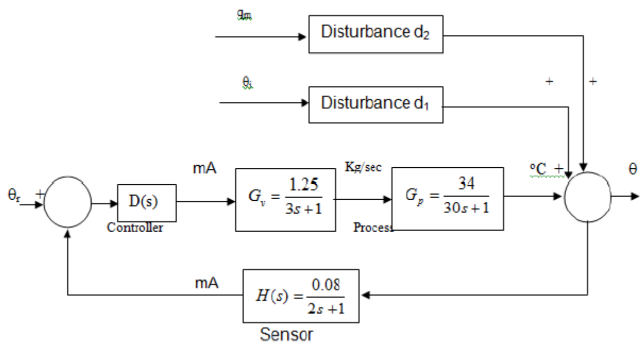

Figure 2: Model of temperature control loop

II. MATHEMATICAL MODELING OF THE SYSTEM

The elements of control loop have been modeled mathematically and tested with process.

(i) Heat Exchanger Dynamics:

In industrial process heat exchanger is used to transfer heat from a hot fluid through a solid wall to a cooler fluid. In the proposed model shell and tube type exchanger is used, which is very adaptable, flexible and can operate over the full range of pressures and temperatures encountered in chemical processes. They are generally composed of a bundle of tubes which are contained in a single jacket called

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"shell". One of the fluids flows in the tubes and the other flows inside the shell around the tubes. Its construction is simple and economical, but the outside surface of the tubes is not accessible for mechanically cleaning.
The mathematical model gives the transfer function which reveal the terms that describe the process response: gain, Time Constant, Dead Time.

In the heat exchanger the fluid that flows through the inner pipe at constant velocity 'v' is heated by steam condensing outside the pipe. The temperature of the fluid entering the pipe and the steam temperature vary according to some arbitrary functions of time. The steam temperature varies with them, but not with position in the exchanger. The metal wall separating steam from fluid is assumed to have significant thermal capacity that must be accounted for in the analysis. The heat transfer from the steam to the fluid depends on the heat-transfer coefficient on the steam side (ho) and the convective transfer coefficient on the water side (hi). The resistance of the metal wall is neglected. The goal of the analysis is to find transfer functions relating the exiting fluid temperature T (L,t) to the entering fluid temperature T (0,t) and the steam temperature Tv(t).

Heat Exchanger transfer function GP(s) relating the outlet temperature Dq to the steam flow Dm and a time constant of 30 sec.

$$\therefore \mathrm{G_P}(s) = \frac{\Delta\theta / \Delta m}{\tau S + 1} = \frac{105/3.1}{30S+1} = \frac{34}{30S+1}$$

Control Valve Dynamics

Control valve implements the decision of the controller. They receive the signal from the controller and accordingly adjust the value of manipulated variable. Commonly used final control element is the air-operated valve, which controls the flow through an orifice by positioning the plug appropriately.
The pneumatic control valve is the most commonly used final control element. In this case Air to close type pneumatic and an equal percentage valve is used. For this valve, the position of the stem (or, equivalently, of the plug at the end of the stem) will determine the size of the opening for flow and consequently the size of the flow (flow rate). The position of the stem is determined by the balance of all forces acting on it. These forces are:
Pd A = Force exerted by the compressed air at the top of the diaphragm.
Kx = Force exerted by the spring attached to the stem and the diaphragm.

$C\frac{dx}{dt} =$ Frictional force exerted upward and resulting from the close contact of the stem with valve packing.

where:
A – Area of the Diaphragm, Pd – Pressure acting on diaphragm, x – Displacement, K – Hook's constant, C – friction coefficient between stem and packing.

The dynamics of a pneumatic valve can be approximated by that of second order system as

$$\frac{x(s)}{P_d(s)} = \frac{A/K}{(1+\tau s)}$$

Diameter of diaphragm = 273 mm (given)
Now evaluation of K:
At steady state, Pd A = Kx; rherefore

$$K = \frac{P_d A}{x}$$

A = 90.73 inch2
K = 15 * 90.73 * 25.4/14.28 = 95.30 psi/mm;
here x = 14.28 mm & Pd = 15 psi.
Control Valve Transfer Function The control valve has a maximum travel of 15mm, linear characteristics and a time constant of 3 sec. The nominal pressure range of the valve is 3 to 15 psig.

$$\mathit{Control\ Valve\ Gain}$$
$$= \frac{\mathit{Range}\text{ of Stem}}{\text{Pr}\mathit{essure}\text{ Range}}$$
$$= \frac{15\text{ mm}}{(15\text{-}3)\text{ psi}}$$
$$= 1.25\ \text{psi/mA}$$

The total transfer-function of Actuator

$$G_v(s) = \frac{1.25}{3s+1}$$

Sensor Transfer Function:

In the system, 3-wire PT-100 RTD with a range of –200 to 600°C is used as it can withstand high temperature while maintaining excellent stability. Temperature coefficient of platinum wire is = 0.00385 ohm per °C. The sensor has a calibrated range of 00 to 2000C and a time-constant of 1 to 2 sec.

Sensor gain

$$= \frac{(20-4)mA}{(200-0)^o C} = 0.08\frac{mA}{^o C}$$

The transfer-function of the sensor H(s)

$$\therefore H(s) = \frac{0.08}{2s+1}$$

Overall closed loop transfer function of temperature control loop from figure 2

$$\therefore \frac{\theta(s)}{\theta_r(s)} = \frac{0.08D(s)\left[\frac{1.25}{3s+1}\right]\left[\frac{34}{30s+1}\right]}{1+K_p\left[\frac{1.25}{3s+1}\right]\left[\frac{34}{30s+1}\right]\left[\frac{0.08}{2s+1}\right]}$$

The analysis of the system with PID controller at set point 1100C, 1150C, 1200C have been evaluated and reported in table 1,2 & 3.

Table 1: Analysis of system with PID controller at set point 110^0 C

S. No.	PID values	Set point	Rise time (sec.)	Peak time (sec.)	Settling time (sec.)
Online response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	110^0C	5	30	180
Theoretical response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	110^0C	4.5	6.94	47.2

Table 2: Analysis of system with PID controller at set point 115^0 C

S. No.	PID values	Set point	Rise time (sec.)	Peak time (sec.)	Settling time (sec.)
Online response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	115^0C	20	60	150
Theoretical response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	115^0C	3.5	5.3	28

Table 3: Analysis of system with PID controller at set point 120^0 C

S. No.	PID values	Set point	Rise time (sec.)	Peak time (sec.)	Settling time (sec.)
Online response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	120^0C	10	45	160
Theoretical response with PID controller	(PB = 5.16, Ti = 7.12 sec., Td = 1.78 sec)	120^0C	3.2	6.18	21.6

III. RESULTS

The closed loop modeling scheme described in this paper gives the response to change in controller parameters (Kp, Ti, Td) and set point (SP) for heat exchanger used in soda recovery section of Star Paper Mill, Saharanpur. The various theoretical responses of the system are compared with online response for different set points. The Rise time, peak time and settling time is calculated using PID controller by varying the set points. The responses for set points at 110, 115 & 120 degree census respectively using step response is shown in figure 3, 4 & 5.

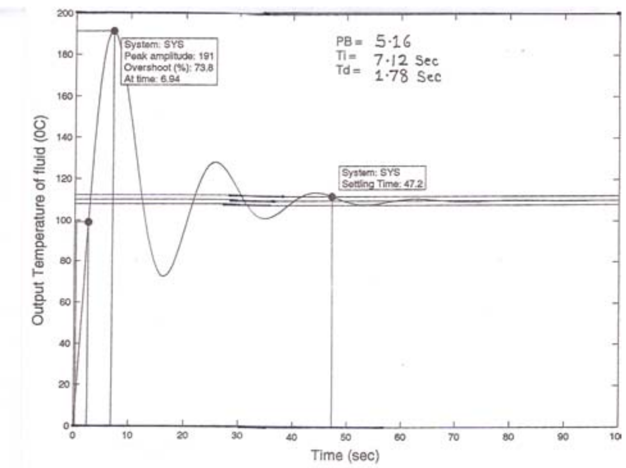

Figure 3: Step response of PID controller at set point 110 degree census

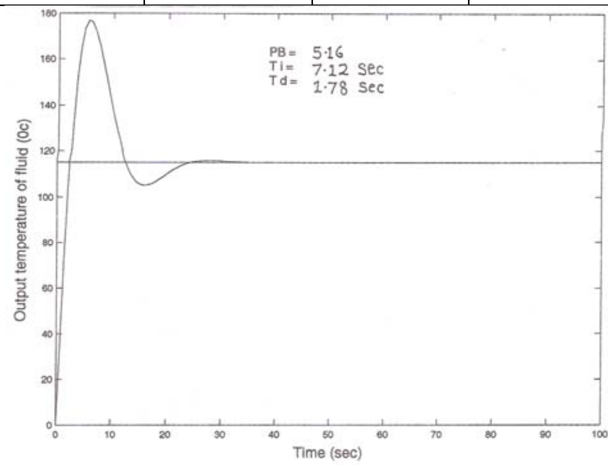

Figure 4: Step response of PID controller at set point 115 degree census

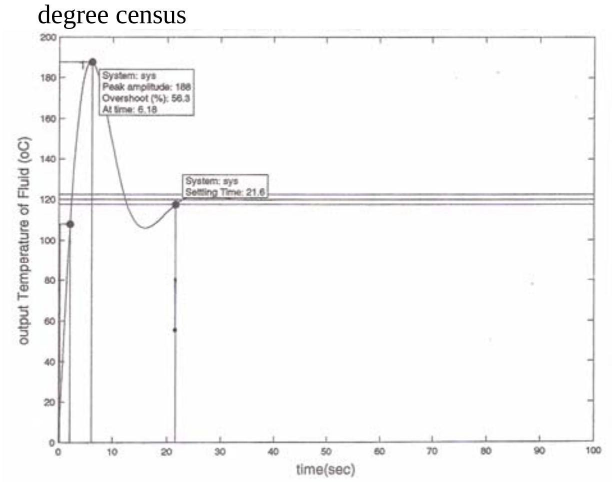

Figure 5: Step response of PID controller at set point 120 degree census

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