

Response Optimization and Control of Shell and Tube Heat Exchanger

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ABSTRACT: In this paper, Model based approach is implemented to control a heat exchanger prototype using optimization technique for parameter tuning of PID controller. Mathematical modelling of heat exchanger is done using mechanical specifications and differential equations of “Shell and Tube heat exchanger”. Optimal PID is used to control the process model. Output response of optimal PID controlled model is compared with ordinary PID controlled model’s output response in results. Response optimization technique is implemented in this process to tune the parameters of the PID controller. It makes the response as a settled one on the desired value and also gives the stable response.

KEYWORDS: PID Tuning, Response Optimization, Shell and Tube Heat Exchanger.

I. INTRODUCTION

Heat exchangers are commonly used in petrochemical industries, gas industries and power plants. These are used for transferring heat between two or more different mediums. The added advantage of these heat exchangers are such as compact structure, high efficiency and low cost. An accurate model describing the dynamic behavior of the system is needed for an optimal operation and control. The controlled variables of the shell and tube heat exchanger are cold fluid temperature and hot fluid temperature. The manipulated variables are inlet flow rate of cold fluid and hot fluid^[4]. The transfer of heat between process fluids is one of the most basic unit operations in the processing industries. Heat exchangers are devices that facilitate efficient heat transfer between two media, thereby changing the temperature distribution of the two mediums when they are in direct or indirect contact. They can transfer heat between a liquid and a gas (e.g., a liquid-to-air heat exchanger) or two gases (e.g., an air-to-air heat exchanger), or they can function as a liquid-to-liquid heat exchanger. It forms integral equipment in a wide range of industries, including power generation, food processing, refrigeration, desalination, air conditioning, automobiles and electronics cooling. Due to nonlinear nature, shell and tube heat exchanger system is hard to model and control using conventional methods^[1].

II. RELATED WORKS

In the chemical and process industries decentralized PID control is one of the most popular control schemes for interacting MIMO plants. The main reason to use this controller is to simple, give good performance and easy to implementation for wide range of process. The tuning of controller in MIMO plant is more complicated because of the interactions between loops. A small change in one loop affects the other loop. The most well-known method for PID tuning for SISO is Ziegler- Nichols (ZN) method in 1942. In this method various instructions are proposed for tuning the PID controller parameters. The method of Niederlinski (1971) is a more natural extension of the ZN tuning procedure of the MIMO processes^[3]. In case of CNOPs, the original PSO method needs to be modified to deal with constraints. A few ideas from the above constraints-handling methods can be adopted. The straightest forward one is the method based on preserving feasibility of solutions. In order to find the optimum in feasible space, each particle searches the whole space but only keeps tracking feasible solutions^[5].

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III. MODELLING OF HEAT EXCHANGER

Related to the energy balance law, the energy supply to heat exchanger must equal to the energy removed. This relationship is given by equation below:

$$T_{ho}(t) = \frac{W_h}{\rho_h V_h (T_{hi}(t) - T_{ho}(t))} + \frac{U_h A_h}{\rho_h V_h C_{ph} (T_{ho}(t) - T_{co}(t))} \quad (2.1)$$

$$T_{co}(t) = \frac{W_c}{\rho_c V_c (T_{ci}(t) - T_{co}(t))} + \frac{U_c A_c}{\rho_c V_c C_{pc} (T_{ho}(t) - T_{co}(t))} \quad (2.2)$$

where,

- T_{ci} , T_{co} , T_{hi} and T_{ho} are inlet and outlet cold and hot fluid temperature respectively ($^{\circ}\text{C}$)
- W_c and W_h are mass flow rate of cold and hot fluid respectively (kg/sec)
- C_{pc} and C_{ph} are the heat capacity of cold and hot fluid respectively (J/ kg. $^{\circ}\text{C}$)
- V_c and V_h are volume of cold and hot fluid respectively (cm^3)
- A_c and A_h are heat transfer surface area of cold and hot fluid respectively (cm^2)
- U_c and U_h are the heat transfer coefficient of cold and hot fluid respectively ($\text{W}/\text{cm}^2 \text{ } ^{\circ}\text{C}$).
- ρ_c and ρ_h are the density of cold and hot fluid respectively (kg/cm^3)

Specifications

Inner Diameter of the shell D_s	=	150 mm
Length of the Shell L	=	615 mm
Number of Tubes n	=	32
Tube inner Diameter d_i	=	12.5 mm
Tube Outer Diameter d_o	=	15.5 mm
Pitch P_T	=	20 mm, Square
Baffle spacing B	=	100 mm
Number of Baffles N	=	4
Area of Collection Tank A_T	=	0.04 sq. m

Logarithmic Mean Temperature Difference (LMTD)

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \quad (2.3)$$

where,

$$\Delta T_1 = T_2 - T_3 \quad (2.4) \quad \Delta T_2 = T_1 - T_4 \quad (2.5)$$

where,

$T_1 \rightarrow$ Hot fluid input temperature

$T_2 \rightarrow$ Hot fluid output temperature

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$T_3 \rightarrow$ Cold fluid input temperature

$T_4 \rightarrow$ Cold fluid output temperature

$$A = \pi d_m L \quad (2.6)$$

where,

$A \rightarrow$ Heat transmission area

$$L = n.l \quad (2.7)$$

where,

$n \rightarrow$ Number of tubes

$l \rightarrow$ Heat transmission length of each tube

$$d_m = 0.5(d_i + d_o) \quad (2.8)$$

where,

$d_i \rightarrow$ Tube inside diameter

$d_o \rightarrow$ Tube outside diameter

$$Q = q_m C_p (T_1 - T_2) \quad (2.9)$$

where,

$$q_m = q_v \times \rho \quad (2.10)$$

where,

$$q_v = F \times (1.667 \times 10^{-5}) \quad (2.11)$$

where,

$F \rightarrow$ Flow rate

$C_p \rightarrow$ Specific Heat capacity

$Q_e \rightarrow$ Heat transfer

$$U = \frac{Q}{A \Delta T_{LM}} \quad (2.12)$$

where,

$U \rightarrow$ Overall heat transfer coefficient

$\Delta T_{LM} \rightarrow$ Logarithmic Mean Temperature Difference

IV. OPTIMAL CONTROL OF HEAT EXCHANGER

The classical optimization techniques are useful in finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions. These are analytical methods and make use of differential calculus in locating the optimum solution. The classical methods have limited scope in practical applications as some of them involve objective functions which are not continuous and/or differentiable.

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Even still, the study of these classical techniques of optimization form a basis for developing most of the numerical techniques that have evolved into advanced techniques more suitable to current practical problems. These methods assume that the function is differentiable twice with respect to the design variables and the derivatives are continuous. Three main types of problems can be handled by the classical optimization techniques:

- Single variable functions
- Multivariable functions with no constraints,
- Multivariable functions with both equality and inequality constraints.

In problems with equality constraints the Lagrange multiplier method can be used. If the problem has inequality constraints, the Kuhn-Tucker conditions can be used to identify the optimum solution. These methods lead to a set of nonlinear simultaneous equations that may be difficult to solve.

Response Optimization Tuning

Step 1: Type `sdotool ('model name')` in comment window. Response Optimization tool will open (Fig.1).

Step 2: Select new in Design Variable Set. Create Design Variable set window will open.

Step 3: Chose the tunable parameters (Kp, Ki, Kd) and press OK.

Step 4: Select new in Requirements and then select Step Response Envelope. It will open a Create Requirement window.

Step 5: Enter the values depending upon our requirements and chose the signal which is to be in control.

Step 6: Select Plot Model Response in Response Optimization window. It will shows the current response of our model.

Step 7: Press Optimize button which is located in right corner of the Response Optimization window.

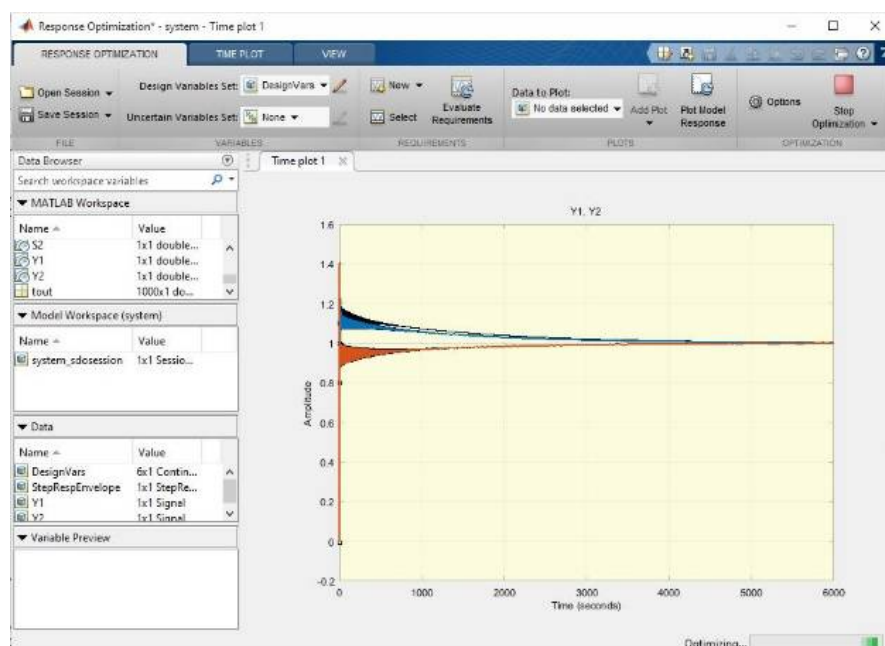


Fig.1 Response Optimization Window

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V. RESULTS AND DISSCUSSION

Results obtained is explained bellow, Figure 2 gives the idea about cold and hot output response vs time. In this, red waveform shows the temperature of the hot outlet in heat exchanger model and blue waveform shows the temperature of the cold outlet in heat exchanger model. Initial temperature of T_{co} is 0°C and initial temperature of T_{ho} is 100°C .

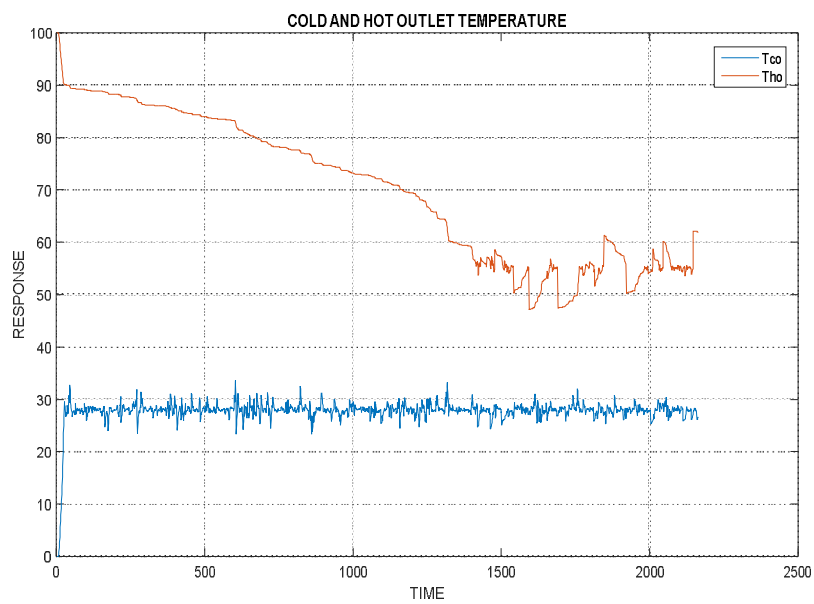


Fig.2 Outputs of Heat Exchanger model

Fig.3 shows the response of Y1 vs time with ordinary PID controller which is not settle in set point also the oscillations are very high.

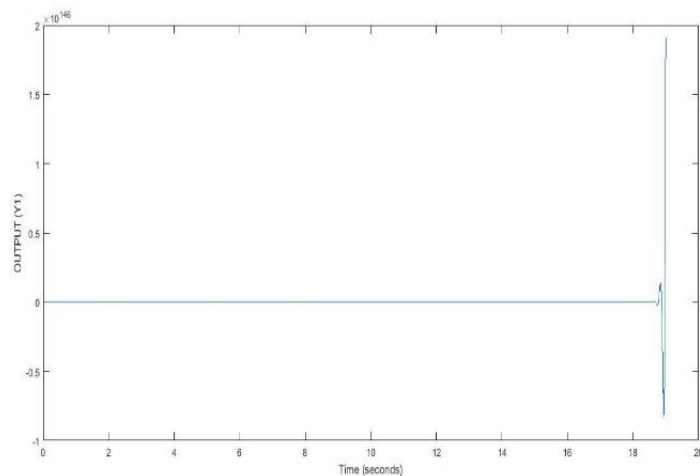


Fig.3 Outputs Y1 of Transfer Function Model with Normal PID

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Fig.4 is the settled response of Y1 with Optimally tuned PID controller, by using optimal PID output Y1 is settled in 2500 sec approximately.

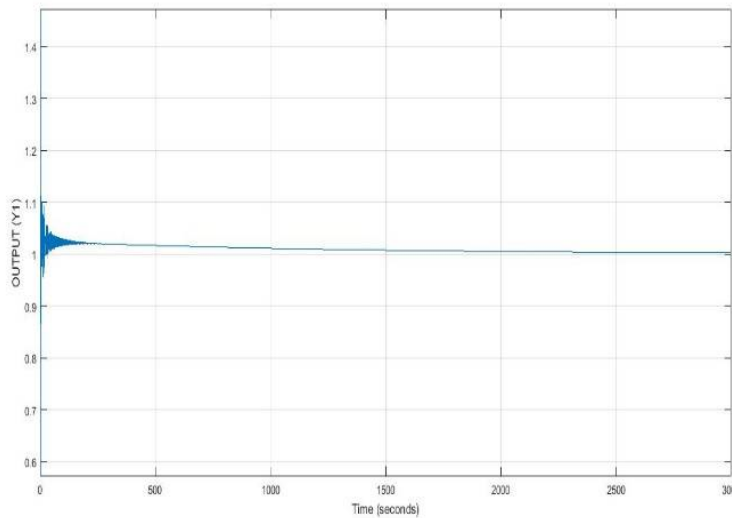


Fig.4 Outputs Y1 of Transfer Function Model with Optimal PID

Table.1 shows the tuning parameters of controller which are tuned using response optimization technique. The optimized values are in the Table.1. Since it is PID controller, the tuning parameters are proportional, integral and derivative gains.

	Controller 1	Controller 2
K_p	0.3674	0.0980
K_i	2.1552	1.0923
K_d	1.0215	0.2533

Table.1 Optimized Tuning Parameters of Controllers

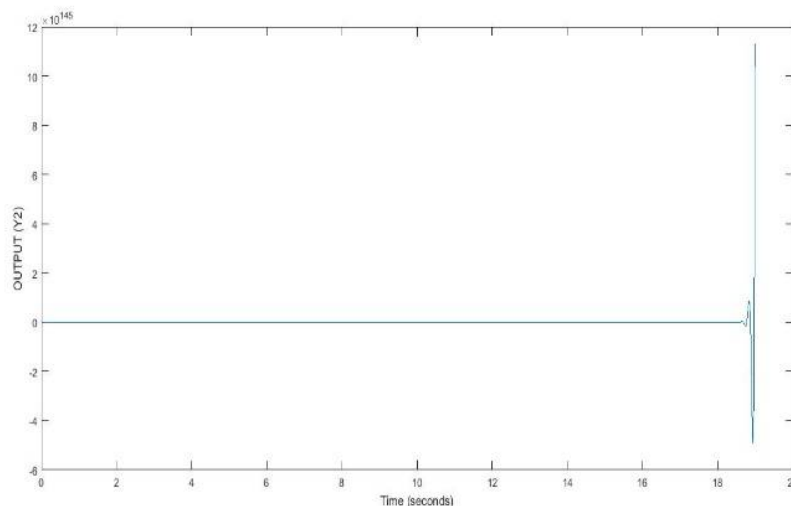


Fig.5 Outputs Y2 of Transfer Function Model with Normal PID

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Fig.5 is non settled response of output Y2 with normal PID controller. Figure 6 gives the Settled output Y2 with optimal PID controller. Tuned parameters are shown below,

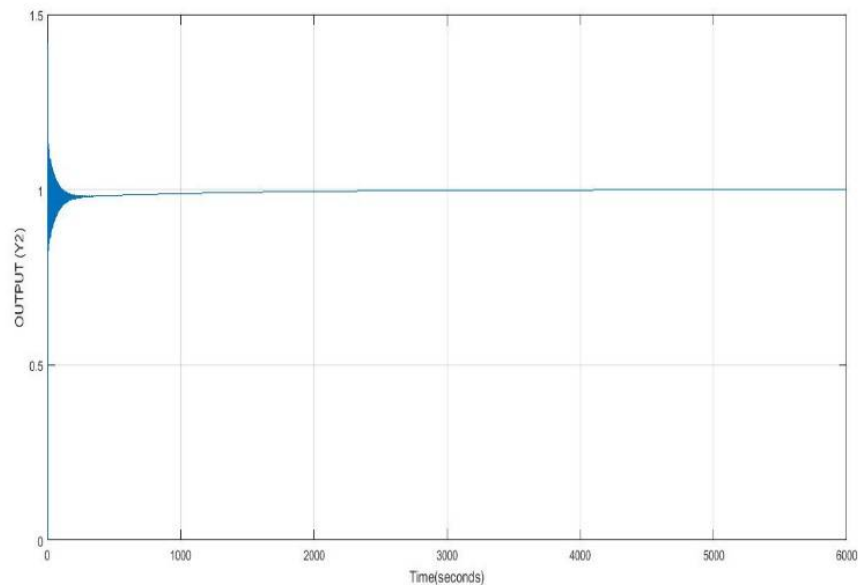


Fig.6 Outputs Y2 of Transfer Function Model with Optimal PID

VI. CONCLUSION

In this paper optimal tuning of PID controller is illustrated. Particularly Response Optimization technique is implemented to tune the parameters of controller. By using this technique process interactions are reduced and makes the system response as a settled one. The final result of system was settled in the set point but the settling time was very high. To reduce that advanced algorithms can be implement in future. That will be the future enhancement of this project.

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