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Improving the Response Performance of Temperature Control Heat Exchanger Process

Ekengwu Ignatius Echezona[#], Utu Ochuko Goodluck[*]
[#]*Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria*
[*]*Department of Welding and Fabrication Technology, Delta State Polytechnic, Ogwashiuku, Nigeria*

Abstract **— This paper has presented improving the response performance of temperature control heat exchanger Process. The mathematical equations representing the dynamics of a shell and tube heat exchanger system were obtained and then modelled in MATLAB/Simulink environment. A proportional integral and derivative (PID) controller that has low pass filter (LPF) added to derivative component called (PIDF) controller was designed using the PID block of Simulink. Robust and fast tuning was performed and the gains of the PID and the coefficient of the LPF were obtained and integrated into temperature control heat exchanger loop. Simulations were conducted for unit step response considering when the designed PIDF was not in the loop (uncompensated) and when it is in the loop (compensated). The result of the uncompensated system indicated sluggish response with rise time of 72.1 seconds, settling time of 133 seconds and overshoot of 0%. In the compensated case, the step response of the outlet fluid temperature was largely improved with rise time of 9.53 seconds, settling time of 15.4 seconds and overshoot of 1.01%. This indicated that the PIDF provided a fast and better tracking response performance to unit step set point.**

Keywords **— Compensated, Heat exchanger system, PIDF controller, temperature control, Uncompensated**

I. INTRODUCTION

Heat exchanger is a thermodynamic system that is used to transfer heat between two or more fluids. The transfer of heat from one fluid to another is an essential operation in key equipment in food processing, petrochemical and pharmaceutical industries. Also, heat exchanger is widely used in refrigeration, power generation, heating and air-conditioning, chemical process, manufacturing, and medical application [1]. There are many factors that determine the dynamics of heat exchanger such as difference in temperature, heat transfer area, flow rate of fluid, and the pattern of flow [2].

As key equipment in many industrial processing plants, the processes taking place in heat exchangers are nonlinear [3],[4]. Controlling the processes is relatively challenging due to nonlinearity and complexity occasioned by many factors like leakage, friction, temperature-dependent flow properties, contact resistance, unknown fluid properties, etc. [4],[5]. There is need for developing a technique that can effectively control a heat exchanger. Many control strategies have been implemented including classical proportional integral and derivative (PID) control, fuzzy logic control (FLC), internal model control (IMC) and others.

There are different types of heat exchanger, among which the shell and tube exchangers are most commonly used heat exchanger equipment. Shell and tube type heat exchanger are mostly applied for wide range of operating temperature and pressure [2]. This type of heat exchanger is characterized by large heat transfer surface to volume ratio than double-pipe heat exchangers, and it is easy to fabricate in a large variety of size and shape [2]. The construction of shell and tube type heat exchanger enables disassembly for periodic maintenance and cleaning.

In this paper, the objective is to implement a temperature controller for a shell and tube type heat exchanger in MATLAB/Simulink. In order to do this, the remaining part of this paper is divided into four, namely: Review of related literature, methodology, simulation result and discussion, and conclusion.

II. REVIEW OF RELATED LITERATURE

Khare and Singh [1] implemented a PID control for heat exchanger system. An internal model based PID controller was developed to control the outlet fluid temperature of heat exchanger plant. The temperature of the output was controlled to a reference value irrespective of the load and process disturbances, equipment saturation and nonlinearity.

Padhee [2] presented controller design for temperature control of heat exchanger system based on simulation studies. It examined the performance of different control techniques like feedback controller, feedback plus feed-forward controller and internal model controller to control the temperature of outlet fluid of a shell and tube heat exchanger system. The performance of the different controllers was analysed in terms of transient characteristics (percentage overshoot and settling time) and error indices. The simulation results indicated that the internal model control scheme outperformed the other control methods.

Dulău et al. [6] presented conventional control versus robust control on heat-exchangers. A robust design method to examine the behaviour of heat exchanger system is presented. Proportional and integral (PI) controller (conventional control) and H-Infinity (robust control) techniques are implemented for the system. The results obtained revealed that the robust control performed better than conventional PI controller in terms of reduced overshoot.

Vaičkaninová and Bakošová [4] presented robust controller design for a heat exchanger using H_2, H_∞, H_2/H_∞ and $\mu-$synthesis approaches. The robust control techniques were applied for a shell and tube heat exchanger and were tested and compared by simulations. The designed robust controllers were with standard PID controller. The result obtained showed that robust controller outperformed the PID especially in terms of disturbance handling.

Emhemed et al. [7] studied the modeling and controller design for temperature control of power plant heat exchanger. Two types of heat exchanger model and controller are studied. The two models are physical model obtained from using real parameter of heat exchanger plant, and second order plus dead time (SOPDT) model derived from the response of heat exchanger. Two different control techniques were developed. The first control technique is a proportional integral and derivative (PID) controller. The second controller is a fuzzy PID (FPID). The PID and FPID controllers were applied to the model. The PID provided the same performance response for both models while the FPID slightly improved the response of SOPDT model compare to PID.

Khan [8] studied modeling and temperature control of heat exchanger process. A ratio controller was developed. The simulation results indicated that the developed ratio controller improved the overshoot from 1.34 % to 0 % and settling time from 148 s to 91.8 s over the feed-forward plus feedback controller.

Sahoo et al. [9] presented modeling and control of a real time shell and tube heat exchanger. It obtained the model of heat exchanger using Auto Regressive-Moving-Average model with eXogenous (ARMAX) inputs from the Pseudo Random Binary Signal (PRBS) experiment conducted on the heat exchanger system. Two classical tuning techniques like relay auto tuning and IMC-based PID tuning were used for designing controllers for the heat exchanger system. Experimental results revealed that the IMC-based PID controller achieved better response performance than relay auto tuned PID in terms of tracking the desired set point.

III. METHODOLOGY

In this section the approach used in realizing the objective of the paper is presented under the following subheadings: dynamic equation of heat exchanger plant, design of PID controller, Simulink block model of heat exchanger process.

A. Dynamic Equation of Heat Exchanger Plant

In order to effectively design a controller for an industrial process, the mathematical equations that accurately represent the dynamics of the process must be obtained. Industrial system are mostly nonlinear in nature and can be approximated as first order plus time delay (FOPTD) or second order plus time delay (SOPTD) models [2]. In this paper, FOPTD model is considered and is given by [2]:

$$G(s) = \frac{K_p e^{-\tau_D s}}{\tau s + 1} \tag{1}$$

where K_p is the process gain, τ_D is the time delay, τ is the time constant of FOPTD. The experimental data used in this paper is presented in Table 1. The schematic diagram of temperature control of a shell and tube heat exchanger is shown in Fig. 1.

EXPERIMENTAL DATA FOR HEAT EXCHANGER SYSTEM [2][10]

Parameter	**value**	**Unit**
Exchanger response to steam flow gain	50	ºC/kgs^{-1}
Time constant	30	seconds
Exchanger response to variation of process fluid flow gain	1	ºC/kgs^{-1}
Exchanger response to variation of process temperature gain	3	ºC/ºC
Time constant of temperature sensor	10	s

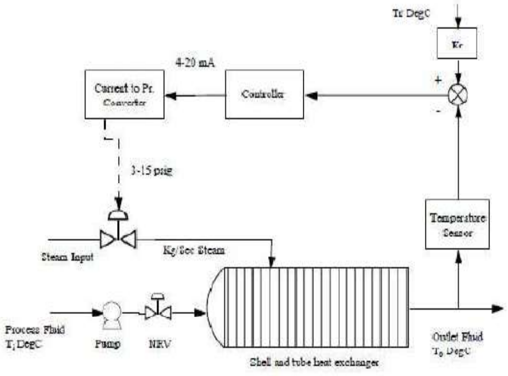

Fig. 1 Temperature control scheme of shell and tube heat exchanger [11]

The transfer function models of the various components of heat exchanger are presented as follows [2]:

1) Heat exchanger transfer function:

$$G_p(s) = \frac{50}{30s+1} e^{-s} \tag{2}$$

2) Valve transfer function:

$$G_v(s) = \frac{0.13}{3s+1} \tag{3}$$

3) Sensor (Thermocouple) transfer function:

$$H(s) = \frac{0.16}{10s+1} \tag{4}$$

4) Disturbance transfer function:

$$G_d(s) = \frac{1}{10s+1} \qquad (5)$$

5) Gain of valve = 0.13

6) Gain of current to pressure (I/P) converter = 0.75

B. Design of PID Controller

A proportional integral and derivative (PID) controller consists of three control laws. These are: Proportional (P) controller, Integral (I) controller and Derivative (D) controller. The mathematical expression for PID control action in time domain is given by:

$$u(t) = k_p e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \qquad (6)$$

where k_p, k_i and k_d are the proportional gain, integral gain and derivative gain. $e(t)$ is the error gain in time domain and $u(t)$ is the control input in time domain. Applying Laplace Transform (LT) to (6) gives:

$$\frac{U(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d s \qquad (7)$$

However, low pass filter (LPF) is introduced to the derivative component of the PID. This gives an extension of PID known as PIDF, which is given by:

$$\frac{U(s)}{E(s)} = k_p + \frac{k_i}{s} + k_d\left(\frac{Ns}{s+N}\right) \qquad (8)$$

where N is the coefficient of the LPF. Auto-tuning using the MATLAB/Simulink PID graphical user interface (GUI) tuner. The structure of the PIDF controller using Simulink block is shown in Fig. 2. The values of the tuned parameters are substituted into in Eq. (8) to give the deigned PIDF in Eq. (9).

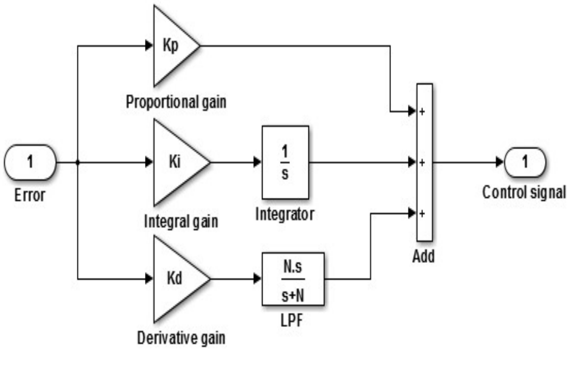

Fig. 2 PIDF Controller Architecture

$$C(s) = 6.53 + \frac{0.176}{s} + 59.6 \times \frac{15s}{s+15} \qquad (9)$$

C. Simulink Block Model of Heat Exchanger System

The system configurations when the PIDF is not added in the loop and when it is added are shown in Fig. 3 and 4. The system configuration in Fig. 3 is called uncompensated system due to the fact the response performance of the outlet fluid is not regulated. In Fig. 4, a compensator (PIDF controller) is added to regulate the reponse performance of the outlet fluid.

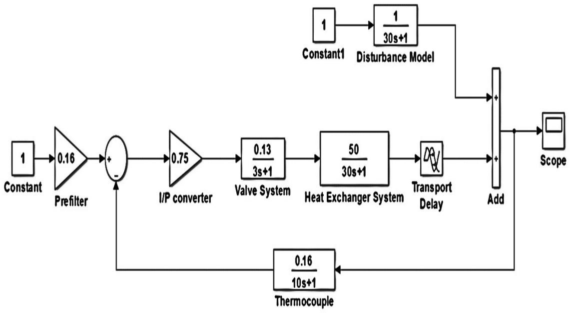

Fig. 3 Simulink model of uncompenated heat exchanger system

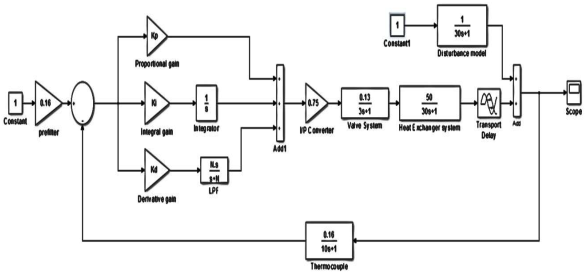

Fig. 4 Simulink model of uncompenated heat exchanger system

IV. RESULT AND DISCUSSION

A. Result

In this paper, simulations have been considered for two cases. The first simulation result shown in Fig. 5 is the case when the system has not been compensated. The second simulation result is the case when the system has been compensated as shown in Fig. 6. Table 2 presents the performance response of the various simulation results.

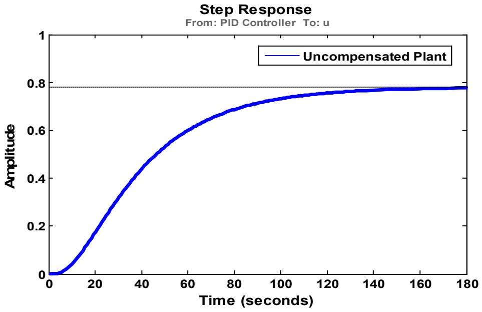

Fig. 5 Step response of uncompenated heat exchanger system

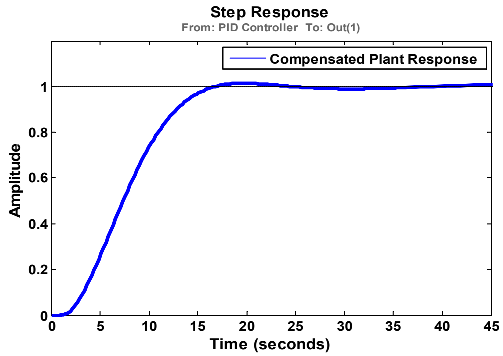

Fig. 6 Step response of compensated heat exchanger system

TABLE 2 STEP RESPONSE PERFORMANCE ANALYSES

Performance parameter	Uncompensated loop	Compensated loop
Rise time	72.1 seconds	9.53 seconds
Settling time	133 seconds	15.4 seconds
Overshoot	0%	1.41%

B. Discussion

The simulation plot shows the temperature control of heat exchanger system to unit step response. In this case the system is uncompensated. It can be seen from the simulation result that response of the system to unit step is sluggish and requires improvement. Table 2 shows that the unit step response performance of the uncompensated outlet fluid temperature control gives rise time of 72.1 seconds, settling time of 133 seconds and overshoot of 0%.

In Fig. 6, the system is compensated with a PID controller with a low pass filter. It can be seen that the designed controller improved the outlet fluid temperature response performance of heat exchanger system. The unit step response analysis of the outlet temperature presented in Table 2 indicated that the controller largely improved the performance of heat exchanger with rise time of 9.53 seconds, settling time of 15.4 seconds and overshoot of 1.41%.

V. CONCLUSION

This paper has implemented a temperature control heat exchanger system using PIDF control algorithm. The objective is to design a temperature controller to improve the outlet fluid temperature of a shell and tube heat exchanger. The dynamic equations of a shell and tube heat exchanger are obtained and then implemented in MATLAB/Simulink simulation environment. The response performance analysis is carried out in terms of rise time, settling time and overshoot. The simulation results indicated that the PIDF largely improve the response of the system.

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