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Modeling and Controller Design for Temperature Control of Heat Exchangers in Power Plants

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Abstract

A heat exchanger is a device that transfers heat from one place to another. Because it can withstand a wide range of temperature and pressure, the power plant heat exchanger is widely employed in chemical and petroleum facilities. A heat exchanger is a device that transfers heat from one place to another. Plant with strong nonlinearity and low dynamics; as a result it is tough to model and manage its dynamics. There are two types of heat exchanger models in this study. For selecting an appropriate model, controllers are used. Controller. (Physical model) is the first model. Generated from genuine heat exchanger plant parameters Second, there's Dead Time plus a Second Order (SOPDT model)This is obtained from the heat exchanger's response. While The controllers are made up of fuzzy proportional controllers. Proportional integral (FPD) controller and derivative (FPD) controller applied to the model as a derivative (PID) controller Their comments are compared to those of the others.

Keywords Power Plant Heat Exchanger, Modelling, Fuzzy Control.

1. Introduction

Heat exchanger operations require advanced control, as these devices are critical pieces of equipment in the petrochemical, food processing, and pharmaceutical sectors, and they are energy-intensive processes [1]. PID, IMC-PID, and MRAC are only a few of the traditional control approaches used in process control [2-6]. PID controllers are used in the majority of power plant control systems.

Unfortunately, utilizing a PID controller that couldn't change the temperature precisely resulted in a lot of inertia and lag [7]. On the other hand, this system has some flaws, including poor robustness and a fixed PID parameter that cannot adjust to changes in the object. Because of nonlinearity, variation, disturbance, and change in objective architecture, the system was unable to achieve good results utilizing the previously specified PID parameter [7][8].

A coefficient diagram method (CDM) based controller would be better suited to dealing with nonlinear control problems than a typical PID controller. In addition, in terms of peak magnitudes of the disturbance error, CDM controller performance is more constant [9]. Another technique, multiple model based Proportional integral derivative control (MM-PID) and multiple model based model reference adaptive control (MM-MRAC) applied for a nonlinear heat exchanger process. MM-MRAC designed on two techniques MM-MRAC with MIT rule and MM-MRAC with Lyapunov rule. MM-MRAC (MIT rule) performs better than MM-MRAC (Lyapunov) since it has better set point tracking [10]. In 2010, Technical report by *Control Station, Inc.* discussed the effect of Proportional P Control, Proportional Integral PI Control, and Proportional Integral Derivative PID Control on heat exchanger process real-time observation. Their study achieved superior enhancement for PI compared to P control. While the recommended tuning correlations for PID control is the Internal Model Control (IMC). Likewise, the control parameters extracted based on FOPDT heat exchanger model and Loop-Pro software is used for fitting the data. The method is easy, effective and thus, there is no wasted time or expense [11]. Robust strategy designed to observe the behaviour of Heat exchanger plant. PI-Ziegler Nichols (PI control) and H-Infinity (Robust control) are used for getting best sensitivity functions. The robust control reduced the overshoot compared to conventional PI control [12].

An adaptive type-2 fuzzy PID control (AIT2FPID) is designed to control the temperature of reactor tank by using a heat exchanger system. AI2FPID designed based on a PID algorithm performs the reasoning through calculating the error and error derivative of the system by using type-2fuzzy inference rules and adjusts the PID parameters by fuzzy rules. AI2FPID technique achieved smooth responses with best disturbance rejection in comparison toclassical PID and MPC [13]. Novel scheme of Neural network model predictive control NNMPC with fuzzy control. The designed scheme is suitable to control different classes of process control such as distillationcolumns, boilers, and reactors, etc. The advantage of the combined NNMPC with fuzzy control is that it is not a linear-model-based strategy and the control input constraints are directly included into the controller synthesis. The disadvantage for this method is the complexity of design and time consuming to create their scheme [14]. The proportional integral fuzzy logic controller (PI-FLC) was constructed using a finite-dimensional approximate model for optimization. Various case studies have been explored based on temperature changes from 25 C0 to 35 C0 and 25 C0 to 50 C0, respectively. In comparison to the traditional controller, the created PI-FLC has shown improvements in terms of faster reach to the set point and disturbance rejection [15]. The use of LabVIEW to build Fuzzy Logic Control (FLC) for a physical heat exchanger operation is a soft computing method. The heat exchanger's FLC was designed using the first order plus dead time FOPDT process identification. LabVIEW was chosen because it offers a better graphical view and is easier to integrate into real-time experiment of

physical heat exchanger process. FLC designed based on first order plus dead time FOPDT process identification of

the heat exchanger. The LabVIEW has been chosen

because it provides enhanced graphical view and easier to

implement to the real-time experimental. The performance indices show the effectiveness of the designed FLC control with better tracking capability [16]. For the Third Order Plus Dead Time (TOPDT) Heat Exchanger system, the Fuzzy C-Means clustering technique is employed with several forms of fuzzy rules. Fuzzy Mamdani and fuzzy Takagi-Sugeno are two examples of fuzzy rules. They compared their results after using the heat exchanger technology, and Mamdani came out on top. The simulation results show that fuzzy control is one of the options for effective heat exchanger control. The nonlinear model [17] was used to create this method. A fuzzy proportional integral derivative controller was created using a genetic algorithm to tune the triangle rules (FPID-GA). Integral error and overshoot are fitness functions related with the system's performance indices. A model of an induction motor control system and a higher level numerical model were used in the simulation studies. The approach, on the other hand, produces promising outcomes, but it is difficult to construct their guidelines [18]. This research focuses on a fuzzy logic paired with a PD controller structure and compares it to a traditional PI controller to show and examine the performance effect for the Physical model and SOPDT model. The heat exchanger's dynamic modelling is presented in Section 2. 3rd section describes the standard Proportional Integral Derivative (PID) control and the Fuzzy Proportional Derivative (FPD) controller's control design structure. The simulation and experimental findings for controlling the heat exchanger plant are discussed in Section 4. The conclusion is then delivered.

2. Mathematical Modelling of Heat Exchanger

A. Dynamic Model of Heat Exchanger (Physical Model)

Heat exchangers come in a variety of shapes and sizes, and they're used to heat and cool fluids in a variety of comfort and industrial applications. The temperature control system of a heat exchanger in a district heating system is a sophisticated process control system with qualities such as high heat inertia, slow time changing, and so on. Figure 1 depicts the system.

Using the provided experimental data, the heat exchanger system, actuator, valve, and sensor are mathematically modelled. The difference between the heat from the hot liquid incoming and the heat flowing out to the product liquid is the heat flow into the tube [19][20]. The following are the equations

$$T_{co}(t) = \frac{w_c}{\rho_c V_c}\left(T_{ci}(t) - T_{co}(t)\right) + \frac{U_c A_c}{\rho_c V_c C_{pc}}\left(T_{ho}(t) - T_{co}(t)\right) \quad (1)$$

$$T_{ho}(t) = \frac{w_h}{\rho_h V_h}\left(T_{hi}(t) - T_{ho}(t)\right) + \frac{U_h A_h}{\rho_h V_h C_{ph}}\left(T_{c}(t) - T_{ho}(t)\right) \quad (2)$$

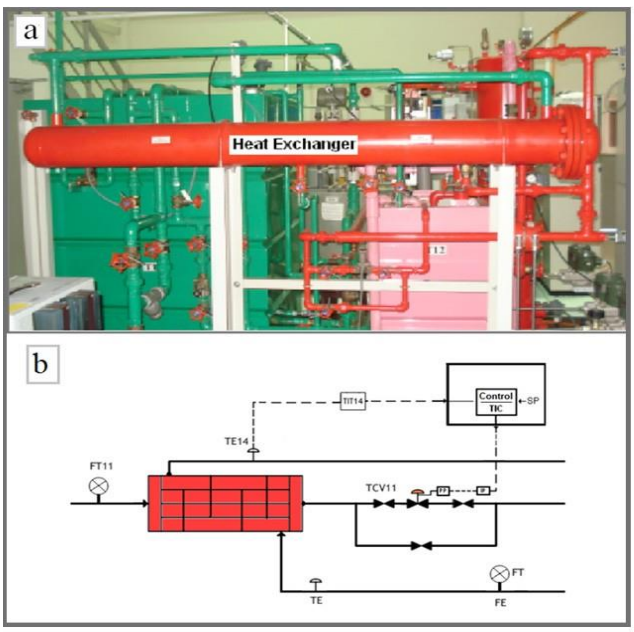

Figure 1. (a) The real power plant heat exchanger, (b) Power plant heat exchanger control scheme.

where T_{ci}, T_{co}, T_{hi}, T_{ho} inlet and outlet cold and hot fluid temperature °C, w_c, w_h is mass flow rate of cold and hot fluid kg/sec, C_{pc}, C_{ph} is the heat capacity of cold and hot fluid J/kg.°C, ρ_c, ρ_h the density of cold and hot fluid kg/cm³ V_c, V_h: volumes cm³ , A_c, A_h the heat transfer surface area of cold and hot fluid cm², U_c, U_h the heat transfer coefficient of cold and hot fluid W/cm^2C^0. The Heat Exchanger plant specifications are listed in the Appendix Table 3.

B. Second Order Plus Dead Time Model (SOPDT Model)

Smith [22] described a method for constructing a SOPDT model based on two points of the system's fraction response at 20% and 60%. The following is the prediction model:

$$G(S) = \frac{k.e^{-t_0}}{(\tau_1 S+1)(\tau_2 S+1)} \quad (3)$$

where, k is the process gain, t_0 is the process dead time, $\tau_1 = \tau\xi + \tau\sqrt{\xi^2 - 1}$, $\tau_2 = \tau\xi + \tau\sqrt{\xi^2 - 1}$.

3. Heat Exchanger Control Design

A. Proportional Integral Derivative (PID) Controller

A PID (Proportional Integral Derivative) controller can increase the system's steady state and transient response at the same time. The PID controller has three terms: a proportional term P for proportional control, an integral term I for a control action proportional to the time integral of the error, and a control action proportional to the time integral of the error. Finally, the derivative term D is proportional to the error's time derivative. The equation for a general PID controller is as follows.

$$\frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (4)$$

where K_p is a proportional gain of the controller and it will have effect for reducing the rise time, but never eliminate the steady-state error. T_i is the integral time that it will have effect for eliminating the steady-state error, butit may make the transient response worse. Next is a derivative time T_d will have effect for increasing the stability of the system [23]. Based on the characterization of Ziegler-Nichols by tangent method of the heat exchanger PID controller values are K_P=5, T_i=24 sec, and Td=6 sec.

B. Fuzzy Proportional Derivative (FPD) Controller

Fuzzy logic is a cutting-edge technique that allows intended system behaviour to be described using everyday language [24]. There are usually three phases to fuzzy logic. Fuzzification, Fuzzy Inference, and Defuzzification are the three methods. All three phases must be used in a typical application. Figure 2 shows a block diagram of the fuzzy logic control system.

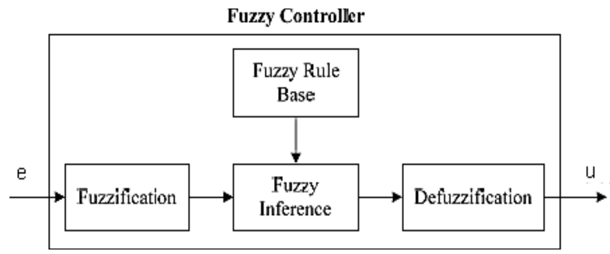

Figure 2. Fuzzy logic block diagram.

A multi-input single output controller paradigm called fuzzy proportional derivative (FPD) control was created. Error (E) and derivative error (DE) are the inputs (DE). Signal control is output (U). At the same time, fuzzy logic controllers can provide desirable dynamic performance for both small and big signals [25]. Figure 3 depicts the structure of an FPD control for a shell and tube heat exchanger.

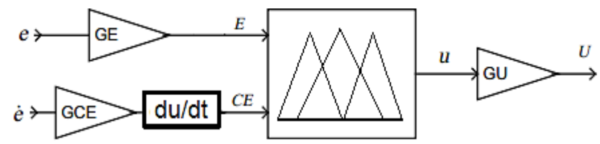

Figure 3. The Fuzzy proportional derivative (FPD) controller structure.

Table 1 shows the structure of fuzzy-PD rules. NE (negative error), ZE (zero error), and PE (positive error) are linguistic terms for error; NLDE (Negative Large Derivative Error), NSDE (Negative Small Derivative Error), ZDE (Zero Derivative Error), PSDE (Positive Small Derivative Error), PLDE (Positive Large Derivative Error) are linguistic terms for derivative error; and (Very High). The input and output membership functions are of the triangular kind. Table 1 shows the format of the FPD controller table created in Matlab/Simulink.

Table 1. Structure of fuzzy-PD controller rule table.

DE \ E	NE	ZE	PE
NLDE	VL	L	L
NSDE	VL	L	M
ZDE	L	M	H
PSDE	L	M	VH
PLDE	M	H	VH

4. Results and Discussion

In practice, the model parameters for a FOPDT orSOPDT models are commonly gained from experiment transient response. These strategies have been used in a variety of process control studies due to their ease of use and effectiveness in obtaining speedier findings through real-time processes. The hot tube's temperature set point has been set at 40°C.

Figure 4 illustrates a similar pattern between the PID control based on the Physical model and the PID control based real time experiment. In comparison to both PID control situations, FPD control had a better performance with no overshoot and a faster trend. Due to the matching of the PID controller responses in both circumstances, the Physical model is able to depict the heat exchanger plant dynamics.

Figure 5 illustrates that the SOPDT model-based PID control has less overshoot than the PID control-based real-time experiment. In comparison to both PID control situations, FPD control had a better performance with no overshoot and a faster trend. Table 2 contains information on the IAE performance index, the overshoot effect, and the time to reach the setpoint.When it comes to PID controls, the Physical model outperforms the SOPDT model. because it gives critical information about the nature and characteristics of real-world system dynamics, which is necessary for the analysis and prediction of system operation That is, a physical model capable of representing the dynamics of a heat exchanger system. With the SOPDT model, however, the FPD control provides a minor improvement.

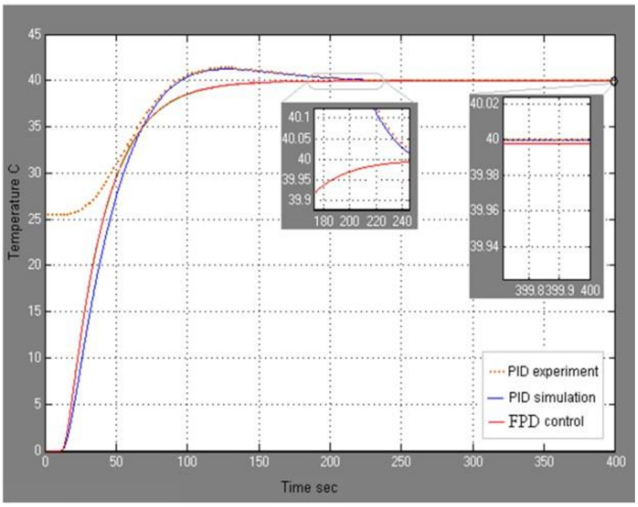

Figure 4. Results of PID Experiment, PID Simulation, and FPD controller (*Physical model*)

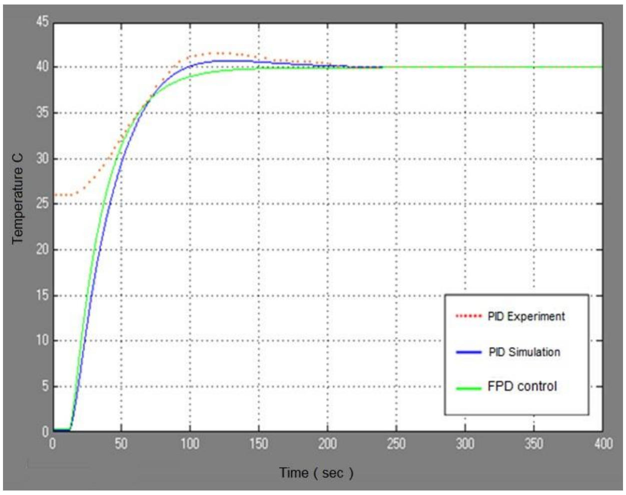

Figure 5. Result of PID Experiment, PID Simulation, and FPD control (*SOPDT Model*).

Table 2. Compare between PID Experiment, PID simulations, and FPD controller

Controller	IAE	overshoot	Rise time	Settling time
PID Experiment	513	3.57%	58 sec	237 sec
PID Simulation *Physical model*	1908	3.42 %	53.4 sec	233 sec
PID Simulation *SOPDT model*	1774	3 %	51 sec	220 sec
FPD control *Physical model*	1766	0%	50 sec	183 sec
FPD control *SOPDT model*	1743	0%	49.3 sec	181 sec

In comparison to the PID controller, Table 2 indicates that models using the FPD controller perform better, with no overshoot and a settling time of roughly 180 seconds. PIDs having a settling time of more than 220 seconds were recorded. The response of the FPD physical model, on the other hand, can reach the model in exactly 50 seconds, with no overshot, no steady state error, and a settling time of 183 seconds.

5. Conclusion

The modelling and control of a power plant heat exchanger system were explored in this work. PID control for the Physical model matches actual time better than SOPDT model, according to the results and debate. That is, a physical model capable of representing the dynamics of a heat exchanger system. With the SOPDT model, however, the FPD control provides a minor improvement. Instead of PID control, FPD control is better for controlling the heat exchanger process.

Appendix

Table 3. Specifications of the Heat Exchanger System

Symbol	Parameter Description	Value
A_c	Heat transfer surface area of cold fluid	9443 cm^2
A_h	Heat transfer surface area of hot fluid	6768 cm^2
T_{ci}	Inlet cold fluid temperature	26 C^0
T_{hi}	Inlet hot fluid temperature	60 C^0
ρ_c	Density of cold fluid	9.9 $\times 10^{-4} kg/cm^3$
ρ_h	Density of cold hot fluid	$9.8 \times 10^{-4} kg$ $/cm^3$
w_c	Mass flow rate of cold fluid	2kg/sec

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