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SELF TUNING AND CONTROL OF PLATE HEAT EXCHANGER VIA FUZZY-PID

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ABSTRACT

Heat exchanger is a device which provides a flow of thermal energy between two or more fluids at different temperatures. The main purpose of heat exchanger is to maintain the temperature of outlet fluid. This paper involves a mathematical modelling for plate heat exchanger using MATLAB. The mathematical modelling can be done by using system identification procedure. Transfer function of a model is obtained from the system identification. The model is simulated using SIMULINK and the PID parameters are obtained by using fuzzy. The results obtained from fuzzy Self tuning PID was successful than comparing to the classical PID controller.

Keywords: System Identification, plate heat exchanger, self-tuning, fuzzy PID.

1. INTRODUCTION

Heat exchangers have a wide range of industrial applications. They are extensively used in space heating, refrigeration, power plants, petrochemical plants, petroleum refineries and sewage treatment [1]. There are many types of heat exchanger designs for various applications. The main types of heat exchanger include double pipe, shell-tube, plate and shell, plate fin, and phase change heat exchangers. The watercourse in a heat exchanger can be arranged as parallel flow, counter flow, and cross flow. New heat exchangers have been designed for emerging thermal engineering fields, such as miniaturized heat exchanger for cooling electronics components and systems, miniaturized heterogeneously catalyzed gas-phase reactions, thermoelectric generators, etc. [2-5]. Vera and Linan [3] analyzed multilayered, counter flow, parallel-plate heat exchangers numerically and theoretically. New materials, such as polymers, have been explored to increase polymer heat exchangers for better fouling and corrosion resistance [6]. Parallel-plated heat exchangers have been considered analytically and experimentally to provide formulations for heat exchanger design. Performance of heat exchanger is monitored by the subsequent methods: i) Outlet temperature of the hot stream (T_{ho}), ii) Approach temperature (T_{ho} - T_{ci}), iii) Log Mean Temperature Difference (LMTD) with time, iv) Heat load profile, and v) Time series of overall heat transfer coefficient. The overall heat transfer coefficient method requires detailed calculations and knowledge of the geometry of the exchangers [7]. PID controllers have been used for several decades in industries for process control applications. The reason for their wide popularity lies in the simplicity of design and good performance including low percentage overshoot and small settling time for slow process plants [8]. Recently, FLC have been successfully applied to a wide range of industrial processes as well as consumer products, and show certain advantages over the conventional PID controllers [9-11]. The field of Fuzzy control has been making speedy progress in recent years. Fuzzy logic control has been extensively exploited for nonlinear, high order & time delay system [12].

This proposed work considers a heat exchanger and builds a SISO model of the system with the help of experimental data. The outlet temperature of the heat exchanger system has to be kept at a desired set value according to the process requirement. Initially a classical PID controller is implemented in a feedback control loop so as to achieve the control objectives. PID controllers exhibits high overshoot which is undesirable. To reduce the overshoot and optimize the control performance, a fuzzy self-tuning PID controller is used along with a feedback controller. The fuzzy self-tuning PID gives a much better result than the feedback PID controller.

2. EXPERIMENTAL SET-UP

The Figure-1 shows the experimental set-up of parallel plate heat exchanger. It consists of plate arranged in parallel manners which are made up of stainless steel. Thus the heat transfer is very large for surface area per unit volume. The rota meters are attached to two sides of the PHE to determine the flow of a fluid. Thus the counter flow is used to determine the model of a system. The thermocouples are used as a sensor to measure the temperature of inlet and outlet fluid. They are attached at the end of a setup to determine the temperature. In counter flow, the hot and cold fluids can be flow in opposite directions where in parallel flow; the hot and cold fluids can be in same direction.

A plate heat exchanger (PHE) is a compact heat exchanger where thin plates (0.5 mm thick, bended 1 or 2 mm) are stacked in contact with each other and the two fluids are made to flow separately along adjacent channels. The plates are made of stainless steel. The flow in a heat exchanger can be arranged as parallel flow and counter flow. Parallel-plated heat exchangers have been considered analytically and experimentally to provide formulations for heat exchanger design.

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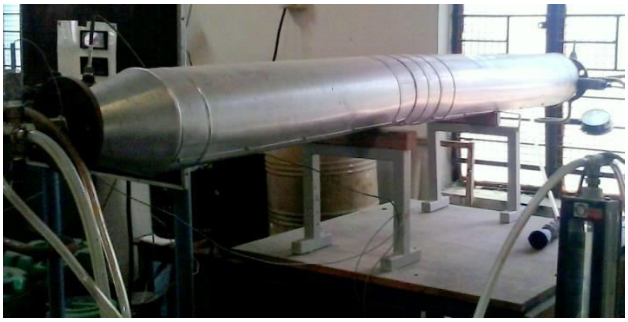

Figure-1. Experimental setup of heat exchanger.

Hot fluid and cold fluids enters channels of the opposite side. Dense array of plates that guide alternating channels of fluids (typically air).Series of fins connect the plates and greatly increase the heat transfer area. The advantage of parallel PHE is very large heat transfer surface area per unit volume. This PHE works as a water to water heat exchanger. Hot water entered at one side and cold water entered at other side of PHE. So heat can be transferred through the plate from water to water. There are many equations that are used in the design of heat exchangers.

$Q_{avg} = U A [LMTD]$ or (1)

Where $Q_{avg}=(Q_c+Q_h)/2$,M represents mass flow rate in kg/hr, C represents specific heat capacity in KJ/Kg.k, Q_{avg} represents heat transfer rate in kw,U represents the overall heat transfer coefficient in kg/secm^2-^{0}c,A represents the heat transfer surface area in m^2,[LMTD] represents the Log Mean Temperature Difference in °c.

$[LMTD]=\Delta T1-\Delta T2/\ln(\Delta T1-\Delta T2)$ (2)

where ΔT1 and ΔT2 are the temperature differences at the two terminal points. The log mean temperature difference (LMTD) is a logarithmic average of the temperature difference between the hot and cold streams at each end of the exchanger. The larger the LMTD, the more heat is transferred. The terminal points are locations at the heat exchanger where the two fluids either enter or leave the heat exchanger. So for a counter flow application; $\Delta T1 = T_{ho} - T_{ci}$ and $\Delta T2 = T_{hi} - T_{co}$ and for a parallel flow application; $\Delta T1 = T_{hi} - T_{ci}$ and $\Delta T2 =$

$T_{ho} - T_{co}$.The heat transfer rate (Q) of the hot or cold water was calculated using temperatures and flow rates. Then the heat transfer area of the heat exchanger (A) was calculated using equation. LMTD for counter flow of cold and hot water was computed with inlet and outlet temperatures of cold and hot water. Based on the calculated values of Q, A, F and LMTD the overall heat transfer coefficient was calculated. The Table-1 shows the experimental readings.

Table-1. Experimental readings

EX.NO	Thi	F_{hi} (LPH)	F_{ci} (LPH)	Tco	Tho
	(°C)			(°C)	(°C)
1	43	75	100	65	40
2	43	75	100	62	35
3	43	75	100	63	33.5
4	60	85	200	60	58
5	60	85	200	62	57.5
6	75	95	100	60	72
7	75	95	100	61	73.5

3. MATHEMATICAL MODELLING

The model of parallel plate heat exchanger applying several physic and chemical laws and variables which are happening in the process. Related to energy balance law, the heat energy supplied is to equal to heat energy removed. This is given by the relation below:

a) Cold water output

$T_{co}(t)=W_c/\rho_cV_c[T_{ci}(t)-T_{co}(t)]+U_cA_c/\rho_cV_cC_{\rho c}[T_{ho}(t)-T_{co}(t)]$(3)

b) Hot water output

$T_{ho}(t)=W_h/\rho_hV_h[T_{hi}(t)T_{ho}(t)]+U_hA_h/\rho_hV_hC_{\rho h}[T_{co}(t)-T_{ho}(t)]$(4)

Where,T_{ci}-cold water input,T_{co}-cold water output, T_{hi}-hot water input,T_{ho}-hot water output,ρ_c, ρ_h-density of fluid,V_c,V_h-volume of the fluid across plates,$C_{\rho c}$,$C_{\rho h}$-heat capacity of cold and hot fluid,W_c,W_h-mass flow rate,U_c,U_h-heat transfer co-efficient.

4. MODEL ESTIMATION

Model estimation of the plate heat exchanger is done in general procedure of system identification such as data examination, model structure selection, parameter estimation and model validation [13]. Data examination is done to obtain a good data. Model structure can be in form of linear, non-linear or intelligent model. Validation is done to validate the estimated model output compare to the real output from the experiments. The model validation can be accepted if it satisfies the percentage of fit and other criterions [14], [15]. The Figure-2 shows the simulation results for the parallel plate heat exchanger. All procedures to estimate the model is done by using System Identification.

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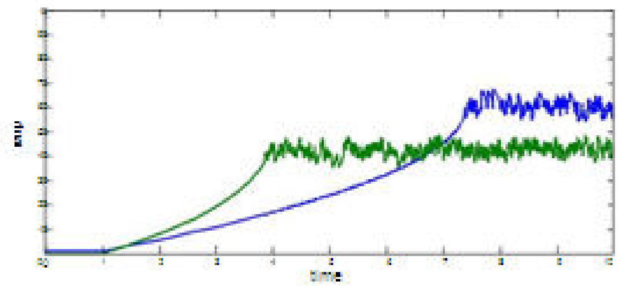

Figure-2. Response of a model.

The model structures are ARX-The simplest model structure that is often a first choice. Enter in Order field: na,nb,nk, the orders and input delays. ARMAX, OE, BJ -Covers a wide family of noise models for single output systems. Here Akaike's Final Prediction Error (FPE) criterion provides a measure of model quality by simulating the situation where the model is tested on a different data set. After computing several different models, compare them using this criterion. According to Akaike's theory, the most accurate model has the smallest FPE.

The structure of a continuous-time process model is a simple transfer function that describes linear system dynamics in terms of one or more of the following elements :Static gain (K_p),One or more time constants (T_{pk}),Process zero (T_z),Possible time delay (T_d) before the system output responds to the input (dead time),Possible enforced integration. Process models are popular for describing system dynamics in many industries and apply to various production environments. The primary advantages of these models are that they provide delay estimation, and the model coefficients have a physical interpretation .Transfer function is ratio of output to input.It is given by

$G(S)=K/(1+T_{p1}s)(1+T_{p2}s)$ (5)

Hence the process model is generated and the transfer function is given by

$G(s)= 43.940/(29.41s^2+10.85s+1)$

Where $K_p=43.940, T_{p1}=5.4595, T_{p2}=5.3863$.

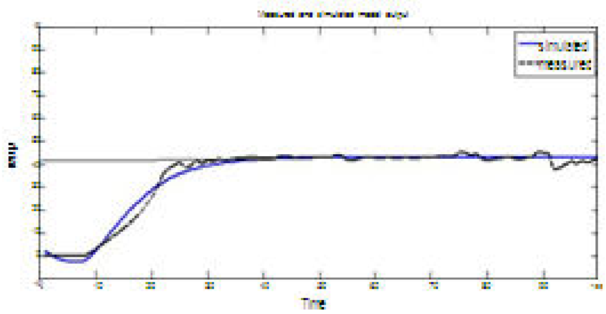

Figure-3. Model output with respect to the measured output.

Thus, the Figure-3 shows the model output with respect to the measured output of a process model. Hence it has best fitness value. Then the model is taken for tuning process.

5. TUNING OF CONTROLLERS

A. Conventional PID controllers

PID controller is still the most popular controller which is widely used to improve the performance in industry, because it's easy to operate and very robust. Latest PID controller's structure is quite different from the original one and the implementation is based on a digital design. The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by tuning value of parameters K_p, K_i and K_d of the PID controller, because each component has it's own special purposes. Mathematically it is represented as

$$y(t) = \left[k_p e(t) + k_d \frac{d(e)}{d(t)} + k_i \int_0^t e(t) d(t)\right] \quad (6)$$

Where: $K_i = K_p/T_i$ and $K_d = K_p .T_i$.

a. Tuning of PID parameters

Tuning of PID parameters refers to the tuning of its various parameters (P,I and D) to achieve the desired response. The basic requirements of output will be stability, desired rise time, peak time and overshoot. In this, Ziegler-Nichols method is used for tuning the parameters and Figure-4 shows the simulation results for PID controller.

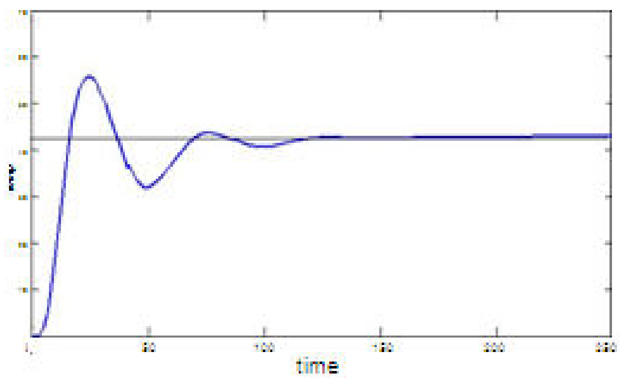

Figure-4. Simulation results for PID controller.

Hence $k_p=37.62, k_i=1.14, k_d=2.85$.The Figure-2 shows the simulation results for PID controller.

B. Self-tuning fuzzy PID controller

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a) Fuzzy logic background

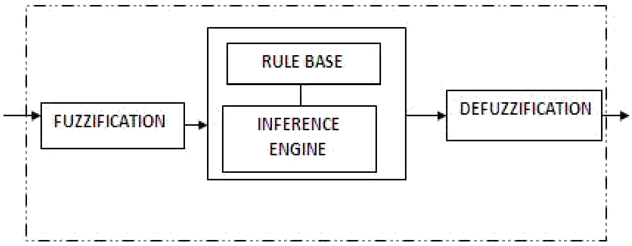

Figure-5. Fuzzy logic controller.

Fuzzy logic controller as shown in Figure-5 consists of main four parts fuzzification, rule base, inference engine and defuzzification. This whole process of decision making is mainly the combination of fuzzy IF-THEN rules and fuzzy reasoning. The inference system makes use of the IF-THEN statements and with the help of connectors (OR and AND).

b) Design and structure of self-tuning fuzzy PID controller

The self tuning fuzzy PID controller, which takes error "e" and rate of change of error"ec" as the input to the controller makes use of fuzzy control to modify PID parameters. Self-tuning fuzzy PID controller means that the three parameters *Kp*, *Ki* and *Kp* of PID controller are tuned by using fuzzy tuner [17], [18]. Figure-6 shows the structure of self-tuning fuzzy PID controller.

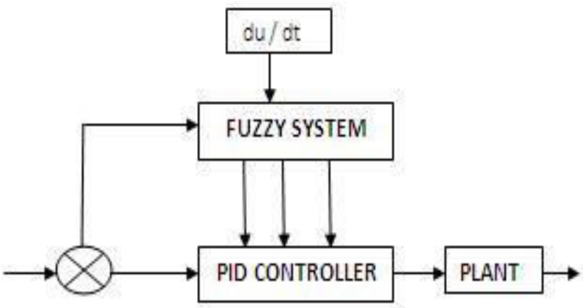

Figure-6. Structure of the self-tuning fuzzy PID controller.

Where e(t) is the error between desired position set point and the output, de(t) is the derivation of error. The PID parameters are tuned by using fuzzy inference, which provide a nonlinear mapping from the error and derivation of error to PID parameters. Adaptive corrections can be made by the following methods,

$K_p = k'_p + \Delta k_p$
$K_i = k'_i + \Delta k_i$
$Kd = k'_d + \Delta k_d$

Table-2. Fuzzy rules for $\Delta k_p, \Delta k_i, \Delta k_d$.

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	**PB**	**PB**	**PM**	**PM**	**PS**	**Z**	**Z**
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

Table-2 shows the fuzzy set rules for the process. The rules designed are based on the characteristic of the heat exchanger and properties of the PID controller. Therefore, the fuzzy reasoning of fuzzy sets of outputs is gained by aggregation operation of fuzzy sets inputs and the designed fuzzy rules. The aggregation and defuzzification method are used respectively max-min and centroid method. Regarding to the fuzzy structure, there are two inputs to fuzzy inference: error e(t) and derivative of error de(t), and three outputs for each PID controller parameters respectively K'_p, K'_i and K'_d. Mamdani model is applied as structure of fuzzy inference with some modification to obtain the best value for K_p, K_i and K_d.The linguistic variable levels are assigned as NB: negative big; NM:negative medium;NS: negative small; Z: zero;PS: positive small;PM:positive medium; PB: positive big. The figure 7 shows the membership function of e,ec,kp,ki,kd.

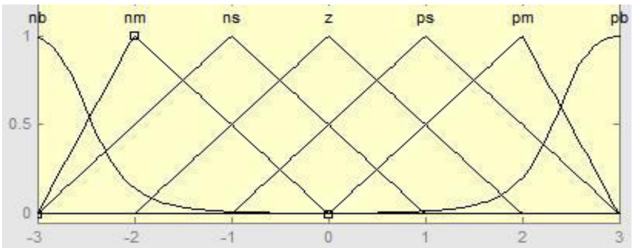

Figure-7. Membership function of e,ec,k_p,k_i,k_d.

6. RESULTS AND DISCUSSIONS

Self-tuning fuzzy PID regulator subsystem block consists of Fuzzy and PID block with some modification refers to the formula which is applied to calibrate the value of K'_p, K'_i and K'_d from fuzzy block to obtain the value of K_p, K_i and K_d. Each parameter has it's own calibration. The value of parameter K_p, K_i and K_d are tuned by using signals from fuzzy logic based on the changes in the error between step signals and output signals. The outputs of the simulation for step input is represented in Figure-8.

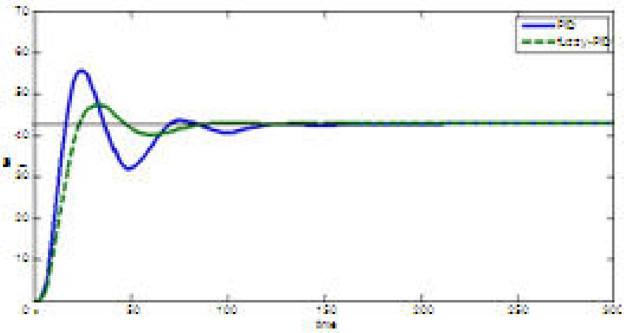

Figure-8. Simulation result of controllers.

Figure-8 shows the performance of the control system with respect to step input signal. The system response to step input compared with conventional PID controller and self-tuning fuzzy PID controller. The self-tuning fuzzy PID controller achieves better tracking response than conventional PID controller. It is indicated from faster rise time, faster settling time, less overshoot and without steady state error.

7. PERFORMANCE ANALYSIS

It shows the comparison of PID and self-tuning fuzzy PID overshoot, rise time, settling time and IAE and ISE. From these, self-tuning fuzzy PID was better than PID response. Table-3 shows the performance analysis of PID and self-tuning Fuzzy PID.

Table-3. Performance analysis of PID and self-tuning fuzzy PID.

S. No	Controller	IAE	ISE
1	PID	163.1	668.3
2	Fuzzy PID	156.5	774.8

The self-tuning fuzzy PID controller improves the performance by slightly decreasing the maximum error (IAE). As the disturbance increases the difference of performances becomes more considerable. The self-tuning fuzzy PID controller is able to eliminate a very big disturbance. The Table-2 shows the improved robustness of the self-tuning fuzzy PID controller.

8. CONCLUSIONS

In this work, mathematical modelling of heat exchanger and self-tuning fuzzy PID controller is proposed. System Identification technique is employed to obtain a linear discrete model. Self-tuning fuzzy controller is applied to tune the value of K_p, K_i and K_d of the PID controller. The amount of overshoot for the response was successfully decreased using the proposed technique. The responses indicate the performance of the system is improved and satisfied when compared to conventional PID controller.

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