Application of LabVIEW and Genetic Algorithm for controlling of Plate Heat Exchanger

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ABSTRACT

The mathematical modeling of plate heat exchanger (PHE) was studied by effect several step change in entrance hot fluid stream and measuring the temperature of exit cold fluid. Based on the energy balance, a mathematical model for this heat exchanger (PHE) was developed. The dynamic behavior in the model showed as a second order overdamped lag and first order lead with a significant delay time. The measurements of PHE streams temperatures indicated that the gross energy transmit factor (U) is linked with the warm fluid stream (mh).

To confirm this model, the control on temperature was applied experimentally and theoretically to the plate heat exchanger using P, PI and PID controllers with some different tuning methods of control parameters; genetic algorithm, Ziegler-Nichols and Cohen-Coon to determine the optimum value for each of these parameters: proportional gain (Kc), factors time (integration (τI) and derivation (τD)). To assess the achievement of control, the time domain specifications such as rise time, overshoot (OS), settling time, measures of control system efficiency (integrates the square of the error over time (ISE) and integrates the absolutes error over time (IAE)) are used.

The PID controller gave better control of temperature than other controllers, While Ziegler – Nichols method gave better control than Cohen-Coon. Genetic Algorithm (GA) technique is the best method in simulation compared with Cohen-Coon and Ziegler – Nichols methods because of the semi-perfect regulation of adjusted parameter values that give lower oscillatory pattern, minimal sum error, but it gives the slower response to reach the steady state.

Keywords: Modeling, Dynamic Behavior, Genetic Algorithm, PHE, Cohen-Coon, Ziegler-Nichols.
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NOTATIONS

A: Area of heat transfer (m^2)

C_p: Heat capacity (J/kg.^{o}C)

G: Transfer function (−)

m_c: Cold water flow rate (Kg/sec)

M_c: Cold water mass (Kg)

m_h: Hot water flow rate (Kg/sec)

M_h: Hot water mass (Kg)

s: Laplace variable (−)

T_{ci}: Inlet cold water temperature (^{o}C)

T_{co}: Outlet cold water temperature (^{o}C)

t_d: Time delay (sec)

T_{hi}: Inlet hot water temperature (^{o}C)

T_{ho}: Outlet hot water temperature (^{o}C)

U: Gross energy transport coefficient (w/m^2.^{o}C)

GREEK LETTERS

ΔT_{lm}: Logarithmic mean temperature difference (^{o}C)
τ_D: Derivative time constant (sec)
τ_I: Integral time constant (sec)

LIST OF ABBREVIATIONS

C-C: Cohen-Coon
FLC: Fuzzy Logic Control
GA: Genetic Algorithm
IAE: Integral Average Error
ISE: Integral Square Error
ITAE: Integral Time-weighted Absolute Error
LabVIEW: Laboratory Virtual Instrument Engineering Workbench
PHE: Heat Exchanger Plate Type
PI: Proportion-Integration
PID: Proportion-Integration-Derivation
PRC: Process Reaction Curve
Z-N: Ziegler-Nichols

1. INTRODUCTION

Heat exchangers are used to control on the fluid temperature by removing or adding heat [1]. Plate heat exchanger (PHE) is apparatus composed of amassed plates separating the cold and hot fluid streams. These plates are either welded or brazed, or have gaskets and are grasped together by a frame. PHEs are used commonly in the chemically and food industry and in many other applications increasingly [2]. The demeanor of plate heat exchangers is paramount to know when they are submitted to passing inflow and to cognize the inflow changes required to applied a controlling system them when take place temperature alterations [3]. Several articles have researched the dynamic behavior and controlling of PHE.

Alwan [4] studied the dynamics of PHE, where he introduced a step-changing on the cool fluid flow rate and noted that the process system is appeared by a first order with a period delay unpretentious to degree the cancelling. Experimental and theoretical analysis of the dynamic features of PHE was introduced by Khan, et al. [5]. They pointed to that the process simulated by a first order and second order with delay time.

They related the exit temperature of the cold fluid flow (T_{co}) with the mass flow rate of the hot fluid flow (m_h) as transfer function were exemplified by an over-damping second order lag with a first order lead has delay period:

$$G(s) = \frac{\bar{T}_{CO}(s)}{\bar{m}_h(s)} = \frac{H(\tau_a s + 1)e^{-t_d s}}{\tau_p^2 s^2 + 2\psi \tau_p s + 1}$$

Al-Zobai [6] studied experimentally the dynamics of HE using step change in stream of hot water and noted its effect on the cold water temperature, then found that the transfer function appeared by first order system plus delay time:

$$G(s) = \frac{0.6\, e^{-0.4s}}{20s + 1}$$

Pratishthananda, et al. [7] suggested a design technique of a GA-based fuzzy supervisory PI controller of a heat exchanger. The activity of the genetic algorithms technique enables the fuzzy logic sets and rules to be optimum defined. He found that the results of design fuzzy supervisory PI controller achieved better than the classical PI controller. Ibrahim, et al. [8] introduced model of a heat exchanger based on experimental data and they applied fuzzy logic control (FLC) by using MATLAB program. In their results they showed that the used control behavior of FLC is to a large degree like to proportional integration control mode but, confers a little improved performance in terms of time characteristics.

Yuvraj and Yaduvir [9] used a classical PID controller tuned by Ziegler – Nichols method to hegemony on the temperature of exit stream of HE device. He controlled the temperature of exit flow of the system by using a model and developed an inner modeling technique based on PID to designed controller regulates the exit flow temperature. He showed that the mathematical model based

PID controller has confirmed 84.1% betterment in overtake (OS) and 44.6% in a stabilization period than the traditional controller.

Al-Dawery, et al., [3] introduced control on temperature of PHE by using classical (PI and PID) and fuzzy control system. They proved in results that the rendering of the fuzzy control system make fleeting responses has minimal the stabilize period and vacillation, when has been compare with the other traditional controller.

Kapil, et al. [10] researched experimentally the controlling system on a heat exchanger. He applied the connectionist systems based control by a LabVIEW program and compared with the conventional PID controller. It detected that the neural network based controller was response in high speed, and the steady-state fault has a minimal than that value in the classical controller. It was noted that, a finite number of studies that had tell the fleeting analyses and the controlling process of PHEs [3].

2. AIM OF THE WORK

On the other hand, little studies were concentrated on a carried out various strategies of controlling by several types of tuning methods inclusive intelligent methods. Thence, the major targets of the current work are:

1- Relate the overall heat transfer coefficient (U) of the PHE with effect of the hot water flow rate (m_h) obtained from experimental work by using LabVIEW program.

2- Carrying out the experimental dynamic behavior by measuring the response of the outlet cold water temperature (T_{co}) under different step changes in hot stream (m_h) compared with the mathematical model results by using MATLAB to carry out model.

3- Picking out the best control parameters by using two execution criteria; the integration squared error (ISE) and integration for time-weight of the absolutes error (ITAE).

4- Applying different control strategies: P, PI and PID controllers with different tuning methods: Cohen-Coon, Ziegler-Nichols and Genetic Algorithm as well as making a comparison among them.

3. EXPERIMENTAL PORTION

3.1 Device

Figure (1) represents the graphical diagram of the experimental system.

3.1.1 Plate Heat Exchanger:

This device made of sheets instead of pipes to segregate the hot fluids from cold fluids. Due to the high heat transfer of the plates, plate type; heat exchanger is very compressed when we compared with a shell and tube heat exchanger with the a similar energy transfer capacity [11,12]. The plate heat exchanger consists of a gasketed mineral sheets bunch, compressed with each other in a frame [13]. This sheets are either smooth or have some form of rippling. In general, these exchangers can't assimilation so high pressures or temperatures [14]. PHE details are cleared in Fig. (2).

3.1.2 Cooling Tower:

The cooling tower has been manufacture has a size of (0.159) m^3. It consists of a reservoir with dimensions of (80×40×55) cm, vertical channel with dimensions of (140×35×30) cm and a fan with diameter 25.5 cm. Cold water is recycled, and the forthcoming (cold) inflow from the exchanger is cooled in the cooling tower and sent to the PHE.

3.1.3 Water Flow Meter:

It has been calibrate the hot and cold flow meter devices prior being utilized in such work to gauge the water influx rate for each try by using standardized cylinder.

3.1.4 Swamp Hot Water Tank:

This tank has a size of (0.07) m^3, has a form is rectangular with the dimensions of (60×45×30) cm. Its exit stream is preserved away as possible from entrance stream to avoid short circuits in the flow.

3.2 The Accessories

3.2.1 Temperature Measurement:

Negative temperature coefficient (NTC) – type thermistors were connected at the entrance and exit pipe lines of both cold and hot sides of the exchanger which able to measure the exchanger temperature response every one second, and in the tank of hot water to measure its temperature for remain it at desired degree by heaters in LabVIEW.

3.2.2 Flow Rate Control Valve:

This valve is a fast running control ball valve from Winner company with the following actuator technical parameters: WRA3-302S+W8BV215 model No., 0-10 VDC input control signal, 24 VAC power, 3 N.m Torque, 8 sec delay time of actuator from fully close to fully open, 2-way and 1/2 in (1.27 cm).

3.2.3 The Mediated Part:

This part is consisting of many portion: collecting kit (can be called 'DAQ'), Transformer, Card Driver, Power Supplies and Signal Card.

The system contained five thermistors. Temperature signals are received from the process by signal card, where it's converted from resistance to voltage and send to NI kit in order to converted voltage to data (analog to digital) reading by computer aid with LabVIEW program. The loads used in process (pump1 - pump2 - heater 1 – heater 2 – extending of control valve and retracting of it) are operated by LabVIEW, where that the order exited from computer as digital and passed through USB, NI kit, card driver and in final received by contactor to operation.

4. MATHEMATICAL MODEL FORMULATION

The modeling for the plate heat exchanger that was applied in the current work is derived below based on unsteady-state energy balance.

Input – Output = Accumulation ……. (1)

4.1 Heat Balance around Cool Plate:

The steady-state heat balancing about cool sheet gives:

$$m^{\circ}{}_c \, C_p \, T^{\circ}_{ci} + UA[(\frac{T^{\circ}_{hi}-T^{\circ}_{co}}{2}) + (\frac{T^{\circ}_{ho}-T^{\circ}_{ci}}{2})\,] - m^{\circ}_c \, C_p \, T^{\circ}_{co} = M_c \, C_p \, \frac{dT^{\circ}_{co}}{dt} = 0 \dots \dots \quad (2)$$

The inclusive heat transfer term is given as:

$$U = \alpha \, m_h^w \ \dots \dots \quad (3)$$

Substituting equation (3) into equation (2) and simplification takes the shape as:

$$m^{\circ}_c \, C_p \, T^{\circ}_{ci} - m^{\circ}_c \, C_p \, T^{\circ}_{co} + Z \, m_h^{ow} \, T^{\circ}_{hi} + Z \, m_h^{ow} \, T^{\circ}_{ho} - Z \, m_h^{ow} \, T^{\circ}_{ci} - Z \, m_h^{ow} \, T^{\circ}_{co} = M_c \, C_p \, \frac{dT^{\circ}_{co}}{dt} = 0 \ \dots \dots \quad (4)$$

Where:

$$Z = \{\frac{\alpha \, A}{2}\} \ \dots \dots \quad (5)$$

The unsteady-state heat balance about the cold plate was:

$$m^{\circ}_c \, C_p \, T^{\circ}_{ci} - m^{\circ}_c \, C_p \, T'_{co} + Z \, m_h'^{w} \, T^{\circ}_{hi} + Z \, m_h'^{w} \, T'_{ho} - Z \, m_h'^{w} \, T^{\circ}_{ci} - Z \, m_h'^{w} \, T'_{co} = M_c \, C_p \, \frac{dT^{\circ}_{co}}{dt} \ \dots \dots \quad (6)$$

The non-linear terms in equation (6) linearized in order to get following eq. :

$$\tau_c \, \frac{d\bar{T}_{co}}{dt} + \bar{T}_{co} = K_1 \, \bar{m}_h + K_2 \, \bar{T}_{ho} \ \dots \dots \quad (7)$$

Applying the Laplace transformation:

$$\bar{T}_{co(s)} = \frac{K_1}{(1+\tau_c \, S)} \, \bar{m}_{h(s)} + \frac{K_2}{(1+\tau_c \, S)} \, \bar{T}_{ho(s)} \ \dots \dots \quad (8)$$

4.2 Heat Balance around Hot Plate:

The same procedure is repeated around the hot plate, and after the linearization the following eq. will be get:

$$\tau_h \, \frac{d\bar{T}_{ho}}{dt} + \bar{T}_{ho} = K_3 \, \bar{m}_h + K_4 \, \bar{T}_{co} \ \dots \dots \quad (9)$$

And after applying the Laplace transformation:

$$\bar{T}_{ho(s)} = \frac{K_3}{(1+\tau_h S)}\,\bar{m}_{h(s)} + \frac{K_4}{(1+\tau_h S)}\,\bar{T}_{co(s)} \quad \ldots\ldots \quad (10)$$

Substituting $\bar{T}_{ho(s)}$ in equation (8) into equation (10) leads to:

$$G_{(s)} = \frac{\bar{T}_{co(s)}}{\bar{m}_{h(s)}} = \frac{H\,(1+\tau_a S)}{\tau_p^2\,S^2 + 2\,\psi\,\tau_p\,S + 1} \quad \ldots\ldots \quad (11)$$

When be seen to arithmetic derivative of the dynamic model of heat exchanger above, it note that the process is represented by first order lead and second order lag term.

5. CONTROLLING SYSTEM FOR HEAT EXCHANGER

The traditional P, PI and PID controllers have been carried out on the hot stream temperature of the plate heat exchanger. The arithmetic impersonation of the P controller is given by:

$$C(t) = K_c\,E(t) + C_s \quad \ldots\ldots \quad (12)$$

For PI controller is given by:

$$C(t) = K_c\,E(t) + \frac{K_c}{\tau_I}\int_0^t E(t)dt + C_s \quad \ldots\ldots \quad (13)$$

And for PID controller is given by:

$$C(t) = K_c\,E(t) + \frac{K_c}{\tau_I}\int_0^t E(t)dt + K_c\,\tau_D\frac{dE}{dt} + C_s \quad \ldots\ldots \quad (14)$$

The superior values of K_C, T_I and T_D selected as a way of Controller adjusting. This predominantly is a particular setting manner and is surely depend on process type. Several of modes have been suggested over a last Half century; however, the Cohen-Coon and Ziegler-Nichols methods were chosen due to its accuracy for a prophecy a optimal control tuning system.

Advanced tuning methods of control are favorite for the time being for controlling several processes in various engineering fields. One of these developed techniques is the genetic algorithm (GA), which it is an optimization technique adapted from innate choose and natural genetics.

The basic notion of genetic algorithm is designed to emulate processes in actual system necessary for evolution, specifically those that follow the principles first laid down by Charles Darwin "survival of the fittest".

6. PERFORMANCE CRITERIA

In classical controller design, the common execution criteria are the integrated of time weight square error (ITAE), integrated absolute error (IAE) and integrated of squared error (ISE), that can be estimated analytically in the frequency domain. The main two methods of the time integral performance criteria used in the proposed work evaluated in terms of:

- **Integral Squared Error (ISE):**
  This index is defined as the integral of the square error, as shown in following eq.:

$$ISE = \int_0^\infty e^2(t)dt \quad \ldots\ldots \quad (15)$$

- **Integrated Time-Weighted Absolute Error (ITAE):**
  This index symbolizes to the integral of the error absolute value but weighted by time as offered in following eq.:

$$ITAE = \int_0^\infty t\,|e(t)|\,dt \quad \ldots\ldots \quad (16)$$

Computation the Gross Energy Transport Coefficient (U)

The rate of energy transport over HE $\mathbb{Q}$ is given as:

$$\mathbb{Q} = U\,A\,\Delta T_{lm} \quad \ldots\ldots \quad (17)$$

Where: A: Area of heat transfer (m^2).

ΔT_{lm}: Logarithmic mean temperature difference ($C°$).

$$\Delta T_{lm} = (T_{hi} - T_{co}) - (T_{ho} - T_{ci})/ln\left[\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}\right] \quad ……. \ (18)$$

$$Ⓠ = U\ A(T_{hi} - T_{co}) - (T_{ho} - T_{ci})/ln\left[\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}\right] \quad ……. \ (19)$$

$$Ⓠ = m_h C_{ph}(T_{hi} - T_{ho}) = m_c C_{pc}(T_{ci} - T_{co}) \ ……. \ (20)$$

$$m_h(T_{hi} - T_{ho}) = \frac{UA}{C_p}(T_{hi} - T_{co}) - (T_{ho} - T_{ci})/ln\left[\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}\right] \quad ……. \ (21)$$

$$(T_{hi} - T_{ho}) = \frac{UA}{m_h C_p}\ \Delta T_{lm} \quad ……. \ (22)$$

7. CONCLUSIONS

In the present article, the arithmetic derivation modeled for the PHE shows a significant behavior of non-linearity. After linearization process on the primary arithmetic equations and converting to the Laplace term, the model shows represented by a transfer function with first order lead and second order lag. And a passable level fit was gained between impractical and empirical responses. Ziegler – Nichols (bode diagram) was more accurate to drive the dynamic model of the nonlinear PHE process, therefore; the controller parameters obtained by bode diagram is better than process reaction curve method, as shown in Fig.(5,6,9 and 10) and table (1,2).

On the other hand, the tuning in simulation by using Genetic Algorithm optimization method is better than the traditional tuning method, as shown in Fig. (7,8) and table (3); it gives a quick response with smaller overshoot and integral square error ISE. Genetic Algorithm optimization method could not be used in the case when the online tuning for controller parameters is required because it has a significant computation time which will be added to the time delay produced from the process and control valve dynamic. Moreover, there are more reasons due to slowing GA compared with the traditional techniques, such as the time it takes inside interface and time of GAs computation.

From each of impractical and empirical applications of the traditional controllers, it resulted that the PID controller has a best performance than the other controllers with two type of tuning methods. By the way, the program (LabVIEW) which used for acquisition these results was showed that it's powerful and versatile programming language for operating and controlling plate heat exchanger process.
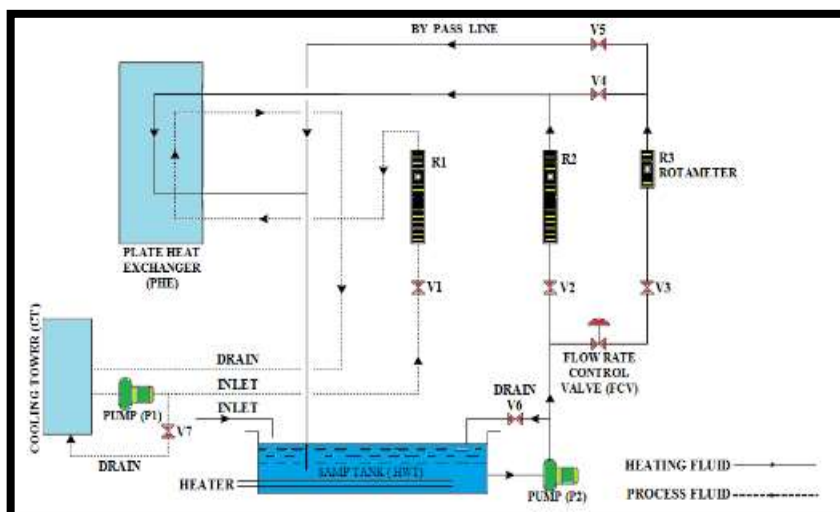

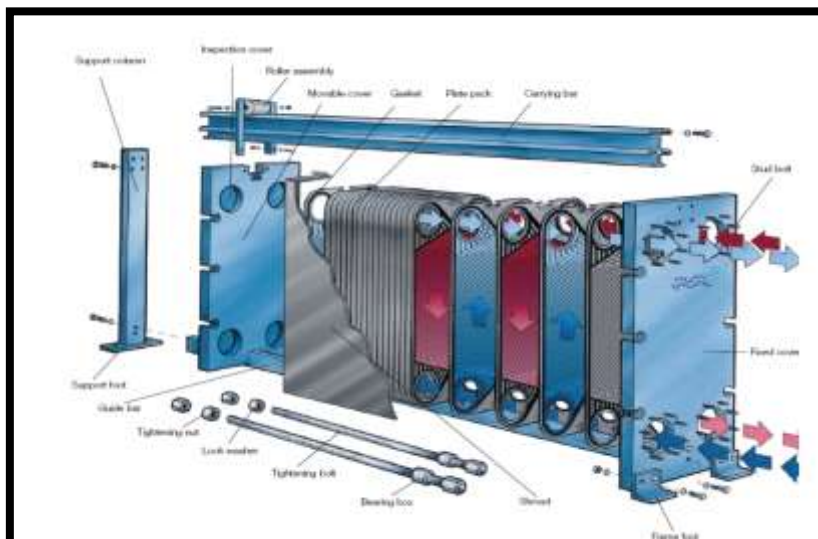**Fig. (1) Schematic diagram of the experimental rig.**

Fig. (2) Plate heat exchanger.

Results Tables and Figures

❖ **Open Loop**

In fig. (3), it has been plotted the values of gross energy transport coeff. (U) versus heated fluid influx rate (m_h).
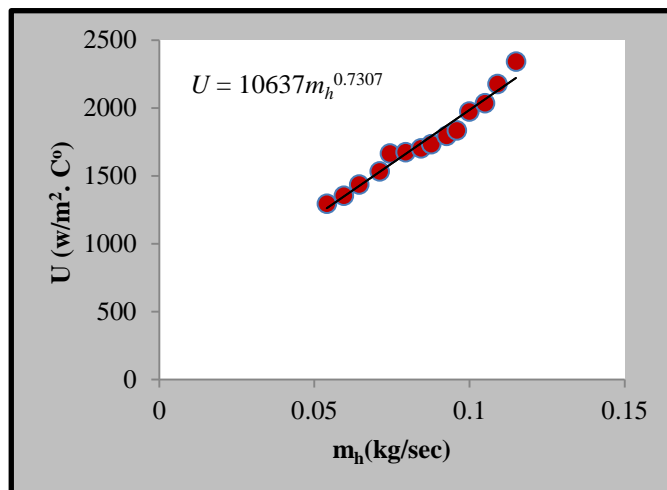

$$U = 10637 m_h^{0.7307}$$

Fig. (3) The relation between universal energy transports coefficient (U) and hot fluid flow rate (m_h).

Prediction Transfer Function of the Process (PHE)

The dynamical responses were study for various step changes in the manipulated variable hot water flow rate (m_h) in order to study the effect of each change on the controlled variable (T_{co}). The theoretical results are compared with empirical data for several step changes and shown in figure (4).
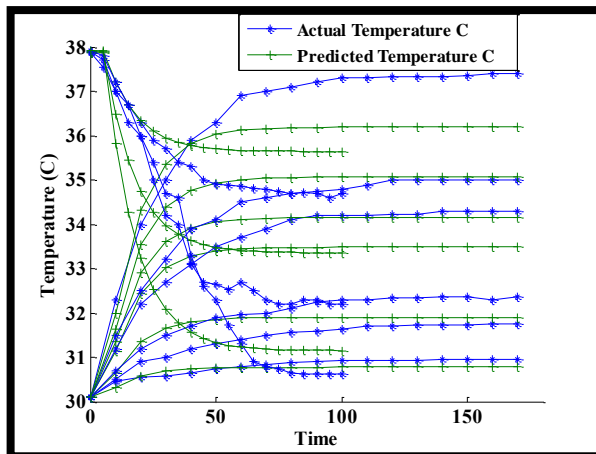
**Fig. (4) Theoretical and experimental process response
for different step changes of input hot water**

❖ **Closed Loop**
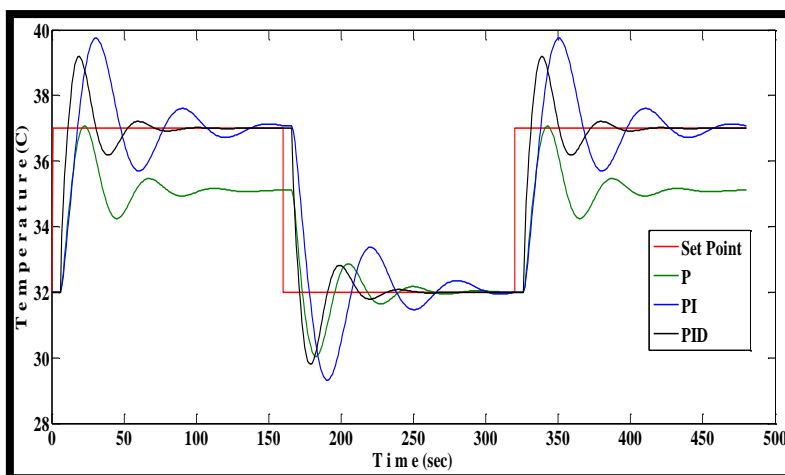   **Theoretical results**

**Fig. (5) Closed loop response of PHE for three controllers
tuned by Cohen - Coon method (step change tracking).**

**Table (1) Differentiation between various parameters
of P, PI and PID control system for PRC method.**

Parameters	PI controller	PID controller
Overshoot	1.5492	1.4403
Settling time	156	66
Rise time	30	19
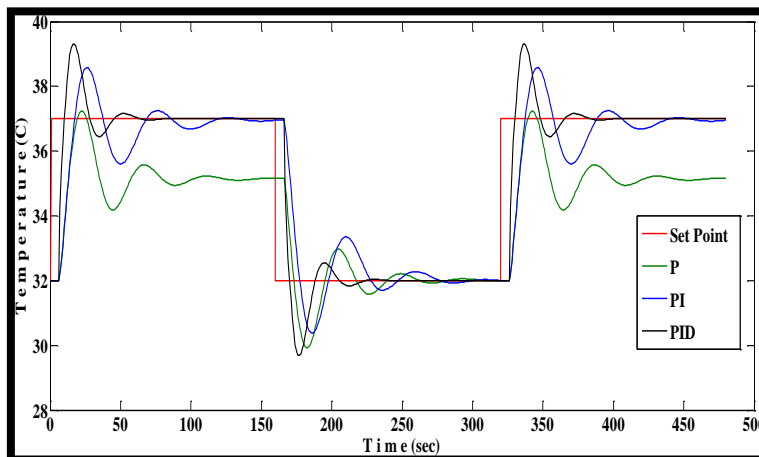
Fig. (6) Closed loop response of PHE controlled by three different controllers tuned by Ziegler - Nichols method (step change tracking).

Table (2) Differentiation between various parameters of P, PI and PID control system for Bode diagram method.

| Parameters	PI controller	PID controller
Overshoot	1.3286	1.4624
Settling time	113	57
Rise time	26	17
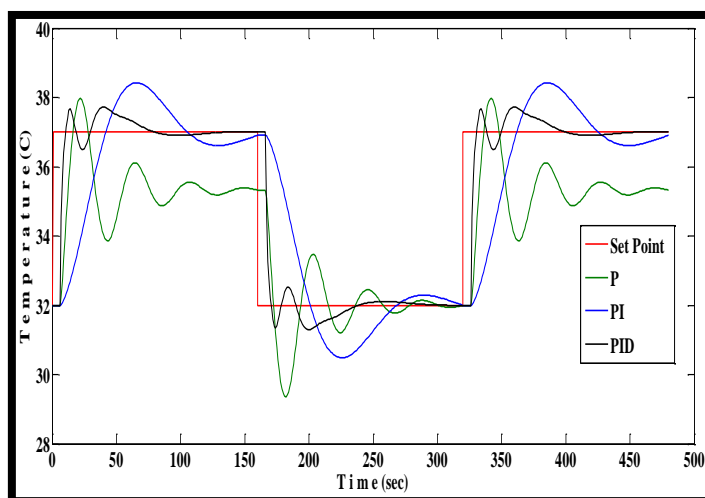
Fig. (7) Theoretical closed loop process response of three controllers (using Genetic Algorithm for set point tracking).
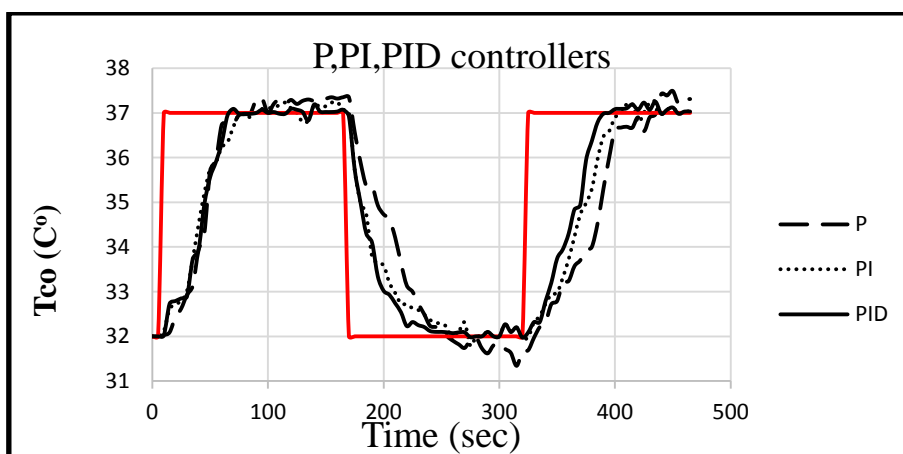
Table (3) Differentiation between various parameters of P, PI and PID control system for GA method.

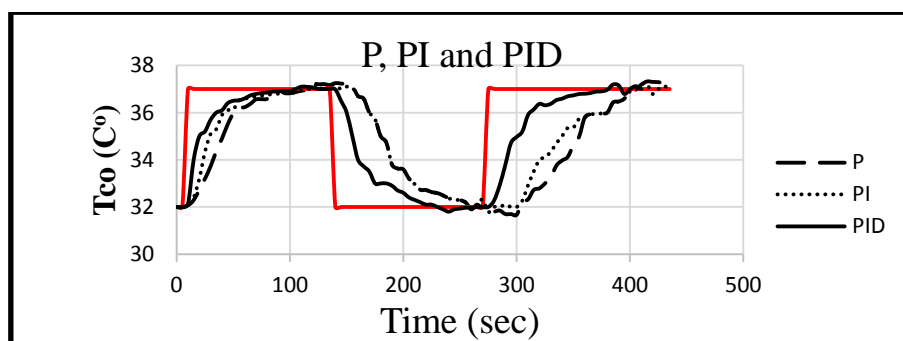| Parameters	PI controller	PID controller
Overshoot	1.2840	1.1406
Settling time	159	72
Rise time	66	40
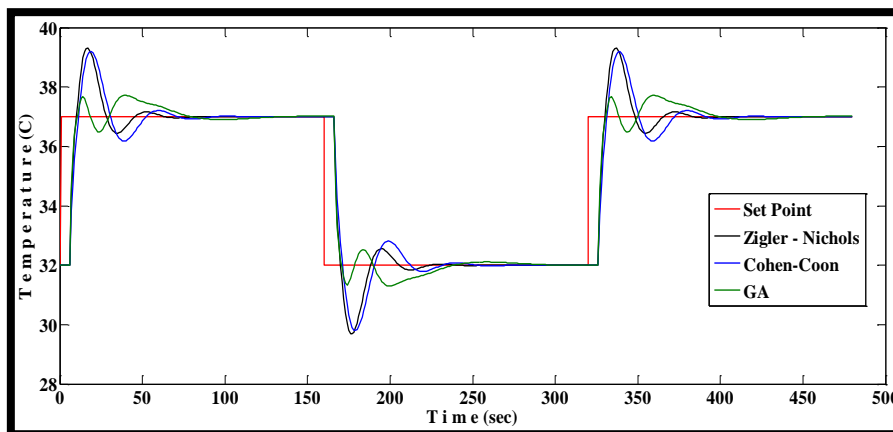
**Fig. (8) Theoretical closed loop process response with
PID controller mode in three tuning methods.**

Experimental Results

**Fig. (9) Experimental closed loop process response with P, PI and PID
controllers tuned by Cohen - Coon method (set point tracking).**

**Fig. (10) Experimental closed loop process response with three
controllers tuning by Ziegler – Nichols method (set point tracking).**

Acknowledgment

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