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PC-Based Controller for Shell and Tube Heat Exchanger

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Abstract

PC-based controller is an approach to control systems with Real-Time parameters by controlling selected manipulating variable to accomplish the objectives. Shell and tube heat exchanger have been identified as process models that are inherently nonlinear and hard to control due to unavailability of the exact models' descriptions. PC and analogue input output card will be used as the controller that controls the heat exchanger hot stream to the desired temperature.

The control methodology by using four speed pump as manipulating variable to control the temperature of the hot stream to cool to the desired temperature.

In this work, the dynamics of cross flow shell and tube heat exchanger is modeled from step changes in cold water flow rate (manipulated variable). The model is identified to be First Order plus Dead Time (FOPDT).

The objective of this work is to design and implement a controller to regulate the outlet temperature of hot water that is taken as controlled variable. The comparison of the designed PI controller with the PC-Based controller performance (according to rise time, percentage overshoot and settling time) shows a good agreement for PC-Based to control the system.

***Keywords*:** PC-based controller, shell and tube heat exchanger, real time controller.

Introduction

PC-based controller is becoming more widespread in process plants and it is characterized by, lower costs which occur in two ways. One, it's much cheaper to combine operator interface and control into one PC-based system than using a PC and a PLC (programmable logic controller). Not only purchased costs are lower, but integration between the PC and the (PLC) is eliminated. The second main cost saving occurs because PCs can outperform similarly priced PLCs [1].

PC-based controller is often achieved via the RS232 interface using simple text strings. Once automation professionals become comfortable with PC-based controller through purchased systems, it's a short step to implementing PC-based controller for control of their own critical processes. For industrial systems, the controller is typically sampling thermocouples directly, and in some cases using a separate data acquisition board, communicating with the controller via a serial port [1].

Shell and tube heat exchangers (STHE) are among the more confusing pieces of equipment for the process control engineer. And their control is difficult yet important problem due to its nonlinearity [2].

The temperature of the two fluids will tend to equalize. By arranging counter-current flow, it is possible for the temperature at the outlet of each fluid to approach the temperature at the inlet of the other. The heat contents are simply exchanged from one fluid to the other and vice versa [3].

In STHE the heat demands of the process are not constant, and the heat content of the two fluids is not constant either. The heat exchanger must be designed for the worst case and must be controlled to make it operate at the particular rate required by the process at every moment in time. The characteristics of the heat exchanger are not constant and vary with time. The most common change is a reduction in the heat transfer rate due to fouling of the surfaces [3]. There is only one variable that can be controlled in this case the amount of heat being

exchanged. In practical situations it is not possible to measure heat flux. It is always the temperature of one fluid or the other which is being measured and controlled. It is not possible to control both since the heat added from one is taken from the other.
To consider which of the streams to manipulated, the complications arise from the fact that exchangers have four ports and involve two different fluids, either of which may change phase. Figure 1 assumes that it is the fluid on the tube side whose temperature is being controlled. As likely as not, it is the one on the shell side issue whose fluid is to be manipulated by changing the flow rate.

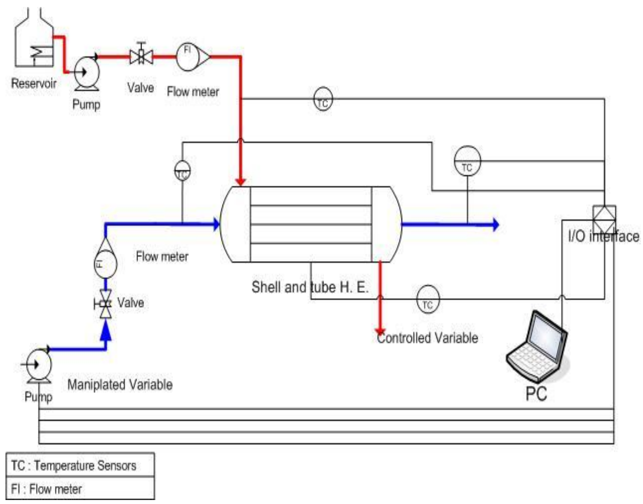

Figure 1. Shell and tube heat exchanger control loop.

Experimental Work

The heat exchanger used in this work is cross flow STHE containing four tubes (14×16 mm), with nine baffles, shell (355×50 mm dia). The Exchanger of 355mm length and 0.06738 m^2 surface area. The hot water is in the tube side while the cold water is in the shell side.
In Figure 1 cold water in 17.2°C is pumped through control valve then flowmeter before entering the shell side of the heat exchanger. While the hot side (tube side) heated water flows from reservoir at constant temperature of 60°C.
Four digital temperature sensors (DS1820) are used to collect the required data. A computer interface is built to demonstrate the feasibility of the concepts with four relays to give the output control signal as in Figure 2.

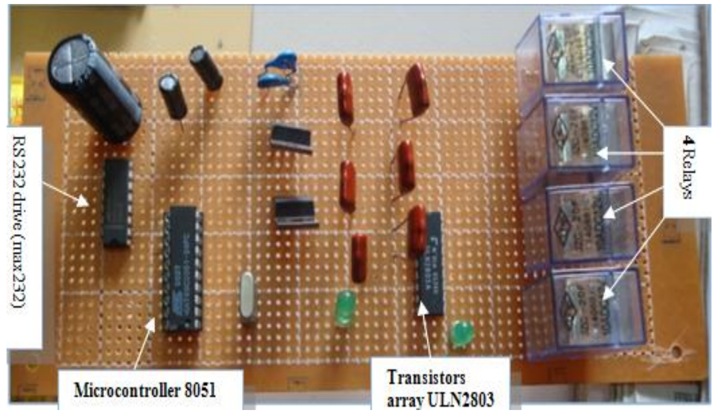

Figure 2. Interface card with 4 input digital temperature sensors and 4 output relays.

Commands for reading temperatures or controlling relays are sent via the RS232 interface using simple text strings to the computer.
This kit can be controlled by sending an electrical signal via simple terminal, communications program (such as HyperTerminal) or via Visual Basic. In this work, the third option is used where a Visual Basic6 program is used to achieve the required tasks. The program is taken from **www.ozitronics.com** and modified specifically for the research problem according to the manipulated variable (pump speed) with four relays and the controlled temperature (output temperature of the hot side) as shown in Figure 3 and Figure 4.

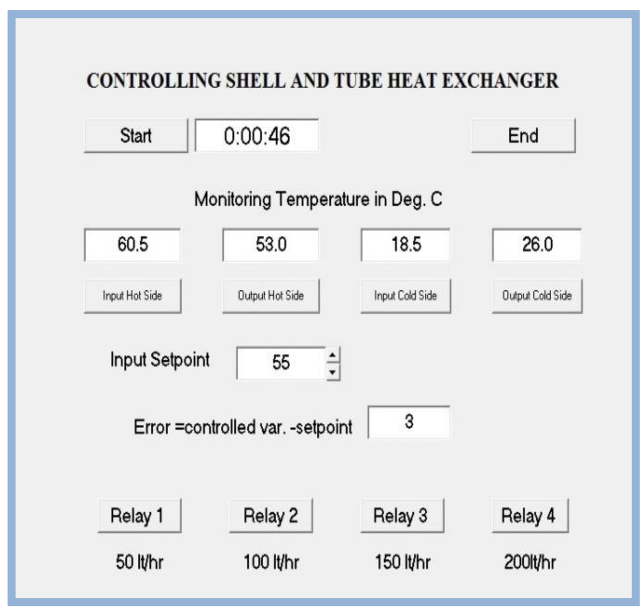

Figure 3. Window of Visual Basic executable program.

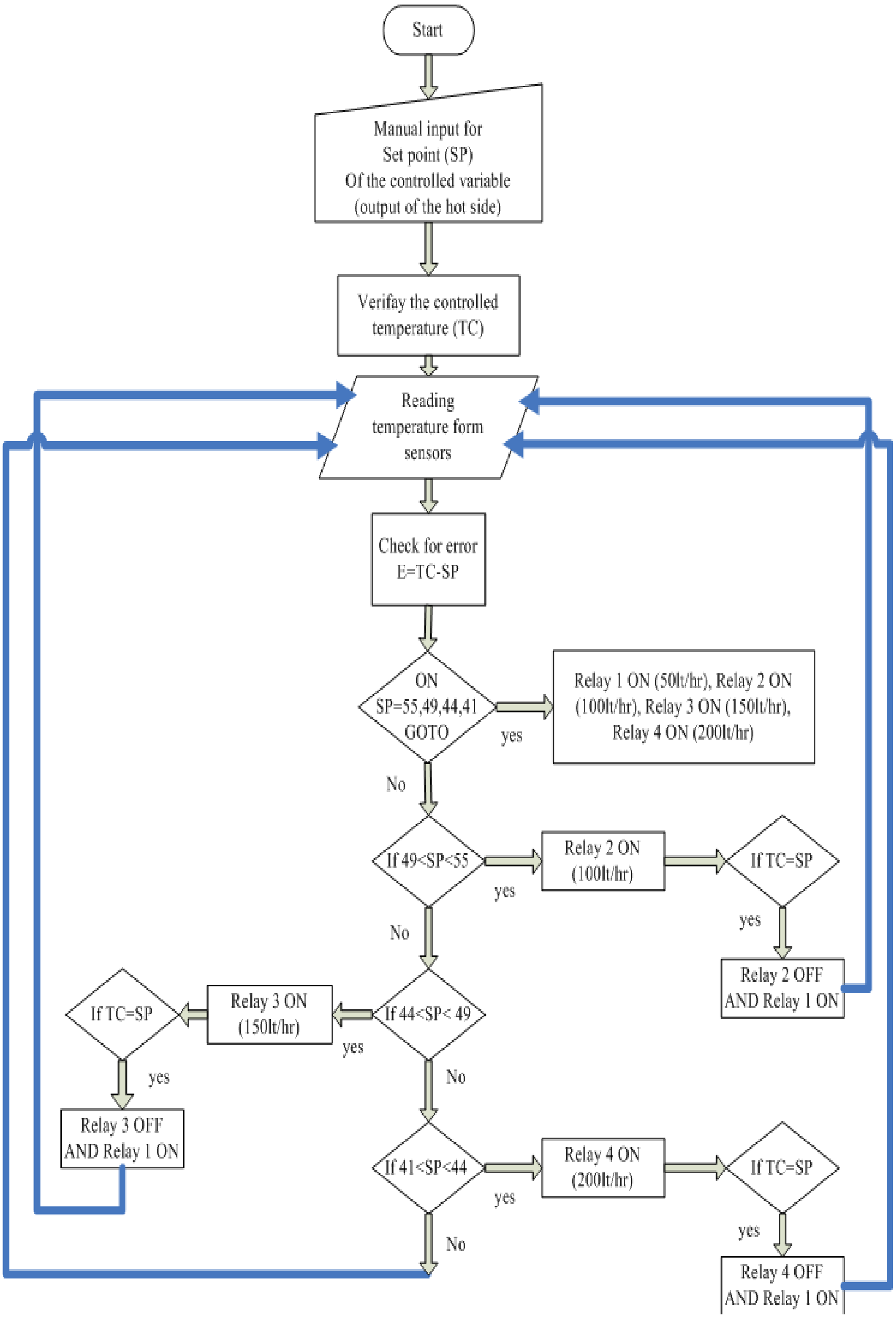

Figure 4. Schematic software specified to control the process.

It is necessary to identify model parameters from experimental data. The simplest approach involves
Introducing a step test into the process and recording the response of the process. Then step changes in cold flow rate of water (18.5 °C) are applied 50-100, 100-150, and 150-200 lit/hr.
The response for the outlet temperature of hot water (entered at 60°C) is shown in Figure 5. It has been recognized that a first order plus dead time (FOPDT) may in general represent process dynamics of the heat exchanger [4].
The calculations are carried further to estimate the Pseudo dead time and the process time constant. Figure 6 shows the open-loop test for the three step changes in manipulating variable flowrate of cold water from 50 to 200 lit/hr. By using the 'two-point method', which does not require the drawing of a tangent line but measures the times at which the process changes by 28.3% (t_1) and 63.2% (t_2) of the total process change[5].
Process time constant $\tau = 1.5\,(t_2 - t_1)$
Pseudo dead time $t_d = t_2 - \tau$

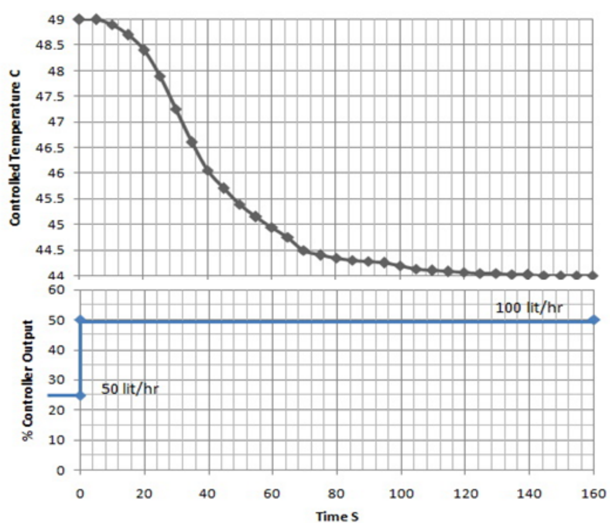

Figure 5. Outlet temperature response of hot water to step change for open loop test for manipulating flow rate 50-100 lit/hr.

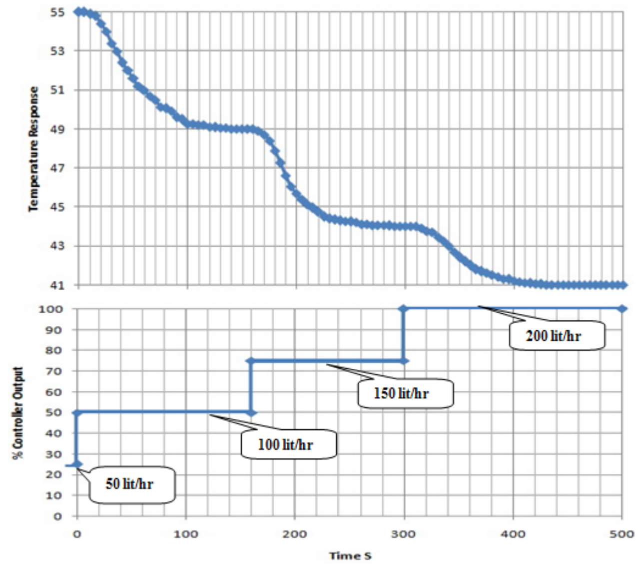

Figure 6. open loop temperature responses with three different step changes 50-100, 100-150 and 150-200 lit/hr.

The values of the t_1 and t_2 are 12 s, and 20 s respectively.
The process parameters are:

$$K = \frac{\text{Steady State Change in the Measured Process Variable}, \Delta y}{\text{Steady State Change in the Controller Output}, \Delta u}$$

$$K = \frac{\Delta y}{\Delta u} = -0.19\ °C/\%$$

and

$$\tau = 36\ s,\ t_d = 19\ s$$

This process has a negative steady-state process gain, and the transfer function of the first order plus dead time (FOPDT) can be deduced as follow:

$$G(s) = \frac{K}{\tau s + 1}\, e^{-t_d s}$$

$$G(s) = \frac{-0.19}{36s + 1}\, e^{-19s}$$

Initial Estimation for Controller Parameters

The design of a controller requires specification of the parameters: proportional gain (K_P), integral time constant (K_I), and derivative time constant (K_D). There is crucial problem to tune properly the gains of PID controllers because many industrial plants are often burdened with the characteristics such as high order, time delays and nonlinearities [6]. Ziegler-Nichols closed loop tuning method is used to find the optimal PID parameters. The optimal parameters obtained for the cold water flowrates are applicable over the entire useful range (50 to 200 lit/hr) which is represents 25% to 100% from the controller output.

The performance of the controller depends as much as on tuning the parameters as its design. Tuning must be applied by the end user to fit the controller to the controlled process. There are many different approaches to controller tuning based on the particular performance criteria selected, whether load or set point changes are most important, whether the process is lag or dead time dominant, and the availability of information about the process dynamics [7]. Traditionally, the problem is handled by a trial and error approach. Design engineers must tune PID controllers manually and usually take considerable time [8]. According to Ziegler-Nichols method [9], the estimation of PID parameters are:

$\underline{K}$= time constant/ (process gain × dead time)

PID: Proportional gain=1.2 × $\underline{K}$, Integral time =2 × dead time, derivative time = 0.5 × dead time

From the formula, the parameters are

K_P=-12 K_I=38 K_D=9.5

To verify the PID parameters, MATLAB-SIMULINK is used to simulate the system depicted in Figure 7. The investigation reveals that the optimum solution is a PI controller with the following

lit/hr

K_P= -7 K_I=0.24 K_D=0.

So the process model compares of PI with the experimental data of PC-based controller are plotted on the same figure (Figures 8-11).

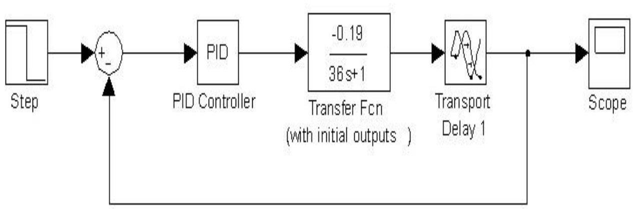

Figure 7. MATLAB Simulink close loop control process.

The optimal parameters are very sensitive to the physical characteristic of the heat exchanger including tubes length and diameter (K_P).

Experimental Results

The constructed PC-based controller is implemented with the heat exchanger system to control the feed rate of cooled side. This is achieved by changing the pump speed to give 50, 100, 150 and 200 lit/hr as manipulating variable to control the temperature of output for the hot side of heat exchanger Figure 8-10 show, respectively, the experimental data that correspond to folwrate changes 50-100, 100-150 and 150-200 lit/hr, Figure 11 give the complete controlled range.

Where the Figure 11 shows the experimental for the STHE run under PC-based controller (continuous line) to study the performance of the controller are subjected to multiple disturbance and compare it along with the conventional controller (dotted line).

Set point changed at time zero from steady state condition of temperature 55 °C of outlet hot stream (50 lit/hr and relay 1 ON) into 49 °C (100 lit/hr and relay 2 ON) for 500 sec long time then the set point changed into 44 °C (150 lit/hr and relay 3 ON) at time 500 sec for another 500 sec period then the set changed at time 1000 sec into 41 °C (200 lit/hr and relay 4 ON) for the rest time.

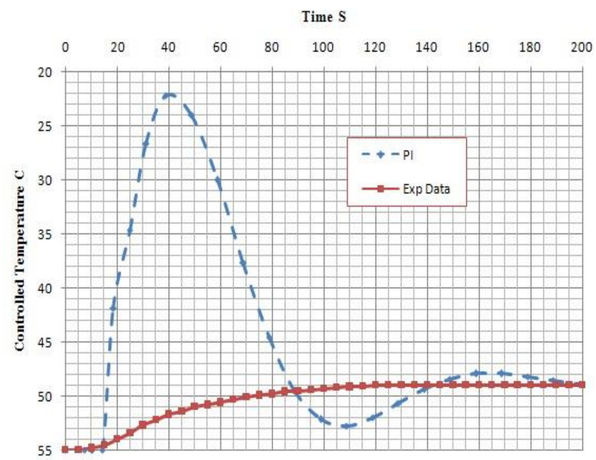

Figure 8. Response for the close loop control process for 50 to 100 lit/hr flow rates of cold side for experimental (PC-based controller) with PI controller.

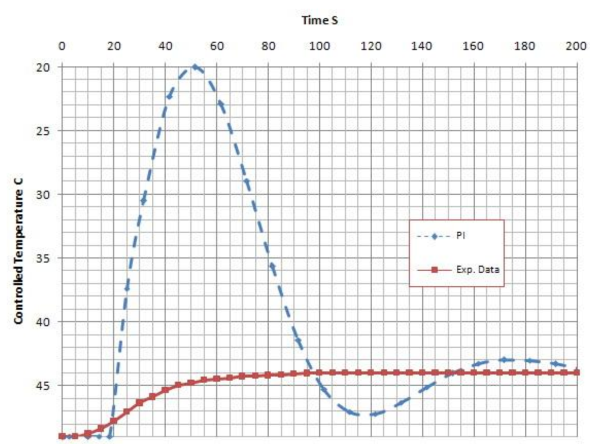

Figure 9. Response for the close loop control process for 100 to 150 lit/hr flowrates of cold side for experimental (PC-based controller) with PI controller.

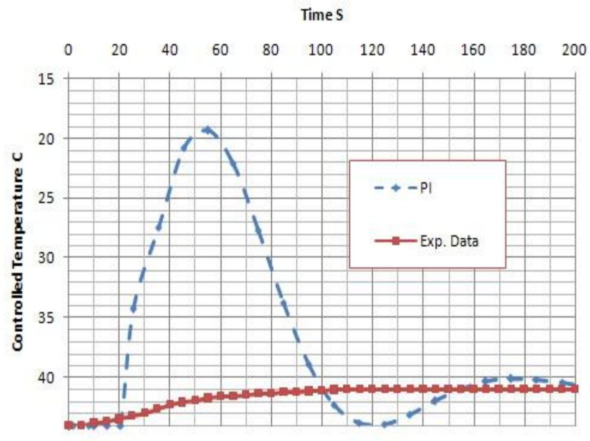

Figure 10. Response of the close loop control process for 150 to 200 lit/hr flowrates of cold side for experimental (PC-based controller) with PI controller.

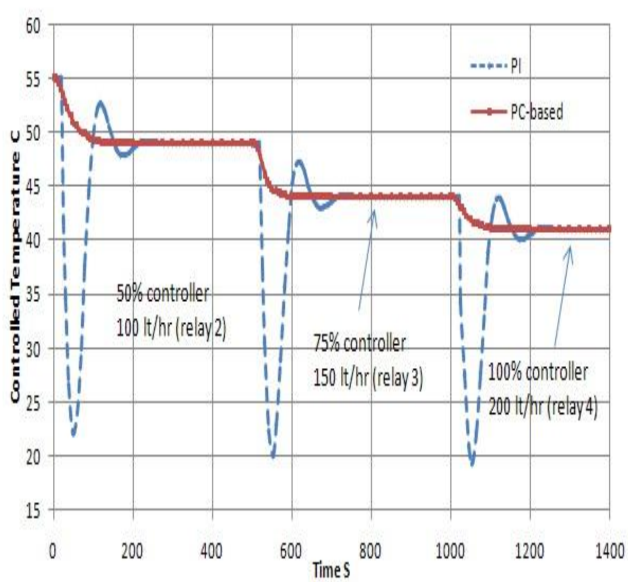

Figure 11. Response for the close loop control process for 50 to 200 lit/hr flowrates of cold side for experimental (PC-based controller) with PI controller.

The data obtained from the calculation for I/O interface and PI is summarized in Table 1 to compare the performance of each controller. It is noted that PI has a faster rise time compared to PC-based controller and need less time to achieve the set point value. PC controller give zero percent overshoot, PI can be retuned by changing the K_P value while PC-based controller can be retuned by changing software architecture.

Table 1. The performance of PI and PC-based controller

	PI controller	PC-Based controller
Rise time t_r	360 s	65 s
Stilling time t_s	~10 s	~100 s
Max. overshoot $\%M_P$	~55	0

The performance of the PC-based controller is studied for different set points in range of 55-41 °C reexamined in terms of rise time 65s, percentage overshoot 0% , and settling time 100.

CONCLUSIONS

Heat exchanger is highly nonlinear process; therefore modeled using two point method to identify the process which is first order plus dead time (FOPTD) and by using Ziegler-Nichols method to estimate the controller parameter and tuned by MATLAB Simulink to give PI controller, PI controller has sensitive proportional gain.
PC-based control was applied to a heat exchanger and compared with proposed PI controller; actually the comparisons are made between the process performance (rise time, percentage overshoot, and settling time). The results show that the PC-based controller is a fast representation for the corresponding processes and PC-based that control the temperature of hot side to the desired set point by manipulating the cold side flowrate using multispeed pump (50, 100, 150 and 200 lit/hr) give an encouraging performance to control the heat exchanger with low cost.

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