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Abstract: The use of Process Reaction Curve (PRC) method for tuning of temperature control parameters in a 10 L stirred tank heater has been studied experimentally. An electric heater was employed as a means to heat the liquid in tank and to maintain its temperature. In order to create a process reaction curve, an open loop experiment was done in laboratory. The electric heat load (q_e) was suddenly changed from 420 Watt (initial value) to 500 Watt (new steady state value) at time equals 2 min. As a result, the liquid temperature in tank rises from 31 to 32 °C at time equals 6 min. This open loop temperature response was then used for tuning of PID temperature control parameters; the tuning results are as follows: gain controller K_c = 77 Watt/°C, integral time constant τ_I = 300 second, and derivative time constant τ_D = 75 second. Furthermore, closed loop simulation using computer programming was also done to evaluate the resulted tuning parameters. The developed mathematical model of temperature control system in stirred tank heater was solved numerically. Such mathematical model was rigorously examined in Scilab software environment. As shown in closed loop simulation, closed loop responses in PID control were faster than those in P and PI controls.

Key words: Closed loop, open loop, PID control, process reaction curve (PRC), stirred tank heater, step input.

Nomenclature

C	controlled variable (°C)
$c_{p1,2,3}$	heat capacity of stream 1, 2, 3 (J/(gr. °C))
e	error (°C)
$f_{1,2,3}$	volumetric flowrate of stream 1, 2, 3 (L/second)
K	steady state gain of the process (°C /Watt)
K_c	proportional gain controller (Watt/°C)
M	manipulated variable (Watt or J/second)
q_e	electric heat/energy (Watt or J/second)
$T_{1,2,3}$	temperature of stream 1, 2, 3 (°C)
T^{SP}	set point of temperature (°C)
t_1	time at which $C = 0.283\ \Delta C_s$
t_2	time at which $C = 0.632\ \Delta C_s$
t_D	effective process dead time (second)
V	liquid volume in tank (L)

Greek letters

ΔC_s	steady state change in controlled variable (°C)
ΔM	step change in manipulated variable (Watt or J/second)
ρ	liquid density (gr/L)
τ	effective process time constant (second)
τ_D	derivative time constant (second)
τ_I	integral time constant (second)

1. Introduction

Stirred tank heater is frequently used in chemical process industries. It can be utilized for examples as a mixing tank and/or a continuous stirred tank reactor. Since its operating conditions change as the disturbances enter the process, the main goal of the plant could probably not be achieved. Therefore, the plant engineers or operators should familiar with

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plant's dynamic behaviors. Additionally, implementation of process control is also very important to operate the plant automatically.

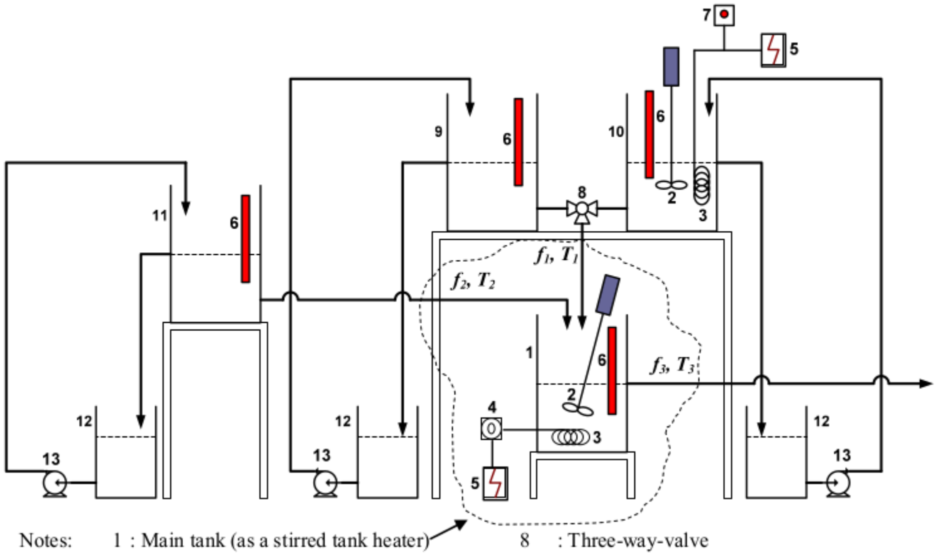
The first activity that should be done before running the plant automatically at its desired conditions is tuning of controller's parameters. Feedback control parameters, such as, proportional gain controller (K_c), integral time constant (τ_I), and derivative time constant (τ_D), seriously affect the stability of the plant. However designed control system must be able to give a stable response in facing the disturbances. Therefore, it is important to study process dynamic and control.

There have been many contributions to the study of process dynamic and control. Temperature dynamic behavior in a horizontal stirred tank heater has been explored [1]. Application of On-Off control in a liquid tank has been done [2]. Tuning of level control parameters using Process Reaction Curve (PRC) and dynamic simulation in a liquid tank has also been done successfully [3].

The goals of this research are to tune temperature control parameters (PID Control parameters) in a 10 L stirred tank heater, and to examine the resulted control parameters through dynamic simulation. In order to achieve the aims of this research, this work was done in two parts, i.e., open loop experiment in laboratory and closed loop simulation using computer programming. PRC was chosen to tune temperature control parameters. The electric heat and the inlet temperature of the tank were selected as a manipulated variable, and a disturbance, respectively. A step input was chosen to make a disturbance, since it can be done easily in laboratory. The Scilab software was utilized to carry out dynamic simulation.

2. Experiment

Fig. 1 shows an experimental apparatus setup. In this work, water was used as liquid to be heated in tank. As can be seen from Fig. 1, No.1 is a main tank that represents a stirred tank heater. The two feeds enter the



Notes:
1 : Main tank (as a stirred tank heater)
2 : Stirrer
3 : Electric heater
4 : Wattmeter
5 : Electricity
6 : Thermometer
7 : Thermostat

8 : Three-way-valve
9 : Feeding tank of stream-1
10 : Tank for making a disturbance
11 : Feeding tank of stream-2
12 : Storage tank
13 : Transfer pump

Fig. 1 Experimental apparatus setup.

tank with a volumetric flowrate f_1 and f_2, respectively, and a temperature T_1 and T_2, respectively. Since the system is designed overflow, the liquid level in tank is always kept constant. The water in tank is heated by an amount of heat q_e (Watt) which is supplied by an electric heater. A stirrer is employed to obtain uniform temperature in tank. The water density is assumed constant, the heat balance in Q model can be written as follows:

$$V\rho c_{p3}\frac{dT_3}{dt} = f_1\rho c_{p1}T_1 + f_2\rho c_{p2}T_2 + q_e - (f_1 + f_2)\rho c_{p3}T_3 \quad (1)$$

where heat capacity of water [J/(gr·K)] is a function of temperature:

$$c_p = 15.33 - 0.1161\,T + 4.514\times10^{-4}\,T^2 + 8\times10^{-7}\,T^3 + 5.206\times10^{-10}\,T^4 \quad (2)$$

In normal condition, stream-1 and stream-2 come from the feeding tank No. 9 and No. 11 in Fig. 1, respectively. PRC experiment is done by changing the wattmeter (No. 4 in Fig. 1) to increase the electric heat load (q_e) rapidly. The liquid temperature response to a change in electric heat load is then investigated. The resulted response will similar with that response given by first order plus dead time (FOPDT) model. PID Control parameters are then tuned by fitting the resulted FOPDT as proposed by Smith [4]. After that, the heat load disturbance is made by changing the inlet temperature of stream-1, T_1, suddenly. This is done by revolving the gate of three-way-valve (No. 8 in Fig. 1), so that stream-1 comes from the tank No 10 in Fig. 1, which is specifically prepared for making disturbance. Again, the liquid temperature response to a change in the inlet temperature T_1 is then investigated. These open loop experiments should be started from its initial (normal) conditions.

In order to evaluate the resulted PID Control parameters, closed loop simulation is carried out by means of computer. For closed loop dynamic simulation, a simple feedback control system is implemented to maintain liquid temperature in tank (T3) constant by manipulating the electric heat (qe). Thus, the equation of manipulated variable can be written as follow:

$$q_e = \bar{q}_e + K_c e + \frac{K_c}{\tau_I}\int e\,dt + K_c\tau_D\frac{de}{dt} \quad (3)$$

where e is defined as:

$$e = T_3^{SP} - T_3 = \text{error} \quad (4)$$

The developed mathematical model of temperature control system in stirred tank heater is solved numerically with the easiest way of explicit euler. The free software Scilab is chosen to carry out the closed loop dynamic simulation. The closed loop responses of temperature control will then be explored in this work.

3. Results and Discussion

Steady state parameters of the stirred tank heater are listed in Table 1. Based on steady state material balance, the process time constant is found 133 seconds (2.2 min). Therefore the system is considered quite sensitive to the changes of input disturbances. Fig. 2 shows the process reaction curve of the influence of electric heat (q_e) on liquid temperature in tank (T_3). Electric heat is rapidly increased by an amount of 80 Watt at time equals 2 min; the temperature T_3 achieves its new steady state value of 32 °C at time equals 6 minutes. This temperature response (Fig. 2) is then fitted (by fit 3) [4] to obtain parameters of FOPDT as shown in Fig. 2. The tuning results of temperature feedback control parameters (P, PI, and PID) are listed in Table 2.

Table 1 Steady state parameters.

Variable	Steady state
Volumetric flowrate of stream-1, $\overline{f}_1$ (L/second)	14.870×10^{-3}
Volumetric flowrate of stream-2, $\overline{f}_2$ (L/second)	22.634×10^{-3}
Volumetric flowrate of stream-3, $\overline{f}_3$ (L/second)	37.504×10^{-3}
Temperature of stream-1, $\overline{T}_1$ (°C)	26
Temperature of stream-2, $\overline{T}_2$ (°C)	26
Temperature of stream-3, $\overline{T}_3$ (°C)	31
Electric heat, $\overline{qe}$ (Watt)	420
Liquid volume in tank, V (L)	5

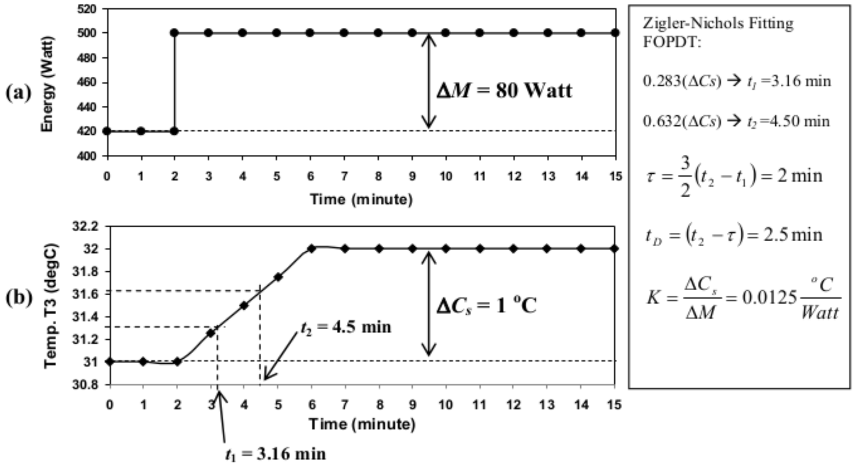


Fig. 2 Process reaction curve: temperature dynamic response to a change in electric heat.

Table 2 Tuning results of temperature controller in A 10 L stirred tank heater (Based on Zigler-Nichols Fitting).

Type of feedback control	Proportional gain Kc	Integral time τ_I	Derivative time τ_D
P	$\frac{1}{K}\frac{\tau}{t_D} = 64\frac{Watt}{^oC}$	-	-
PI	$\frac{0.9}{K}\frac{\tau}{t_D} = 57.6\frac{Watt}{^oC}$	$3.3t_D = 8.25\text{ min} = 495\text{sec}$	-
PID	$\frac{1.2}{K}\frac{\tau}{t_D} = 77\frac{Watt}{^oC}$	$2.0t_D = 5\text{min} = 300\text{sec}$	$0.5t_D = 1.25\text{min} = 75\text{sec}$

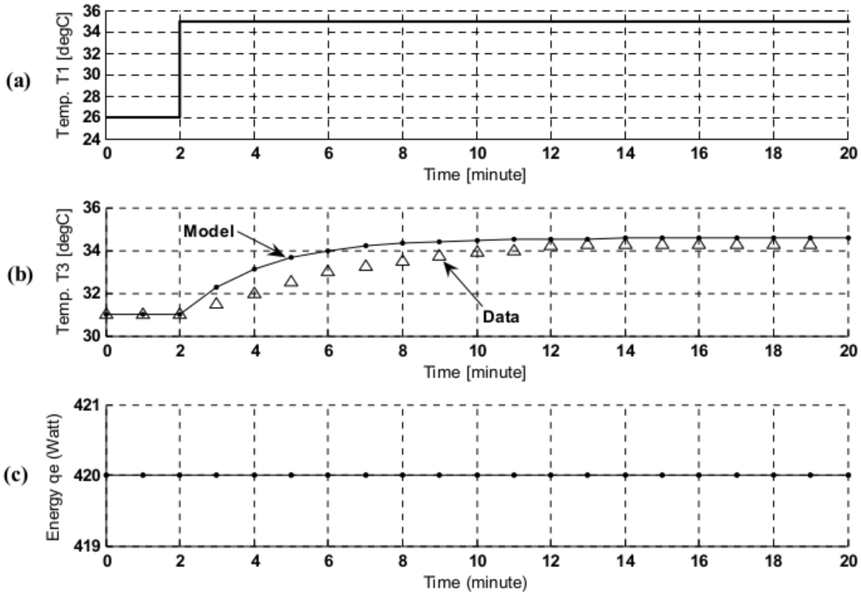


Fig. 3 The open loop responses to a change in the inlet temperature of steram-1 (T_1): (a) temperature of stream-1 (T_1), (b) liquid temperature in tank (T_3), (c) electric heat (q_e).

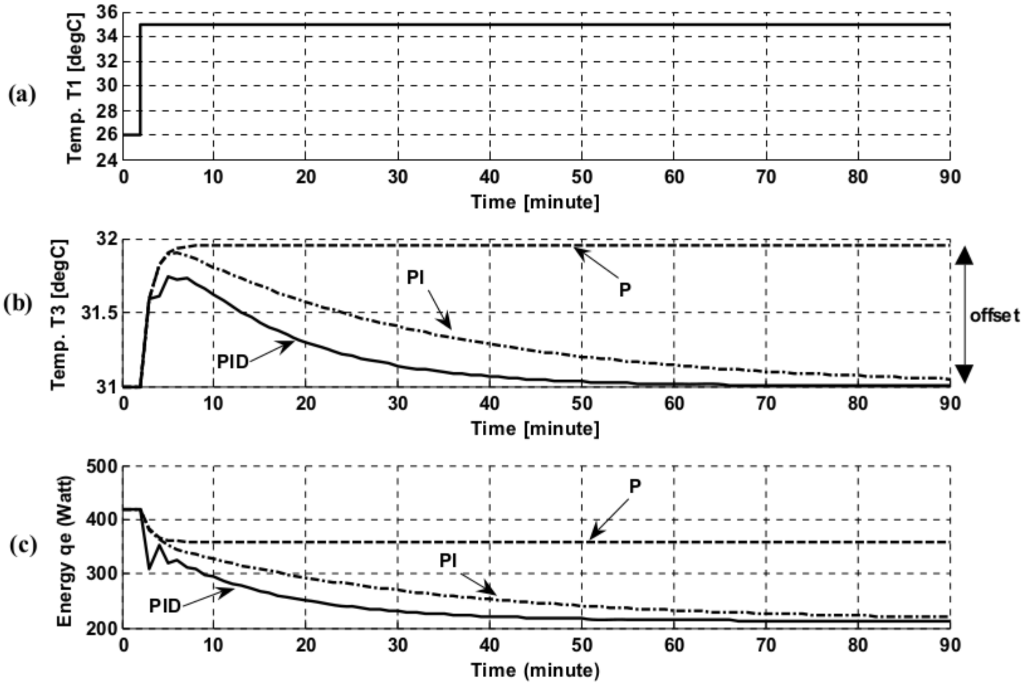


Fig. 4 Closed loop responses to a change in the inlet temperature of steram-1 (T_1): (a) temperature of stream-1 (T_1), (b) liquid temperature in tank (T_3), (c) electric heat (q_e)

Fig. 3 shows the open loop responses to a change in the inlet temperature of stream-1 (T_1). The inlet temperature T_1 is increased by an amount of 9 °C at time equals 2 min (Fig. 3a). Since the electric heat is constant (Fig. 3c), it is understandable that liquid temperature in tank (T_3) rises to a new steady state value of about 34.2 °C at time equals 10 min.

Closed loop responses to a change in temperature T_1 are illustrated in Fig. 4. As can be seen from Fig. 4, the temperature controller (P, PI, and PID) attempts to return temperature T_3 to its normal value of 31 °C. Temperature T_3 can be returned to its set point by both of PI and PID Controls. However P Control still produces an offset of 0.9 °C. Closed loop response of PID Control is fastest compared to P and PI Controls; Temperature T_3 can be returned to its set point at time equals 60 min.

4. Conclusions

This paper has discussed tuning of temperature control parameters in a 10 L stirred tank heater. This research gave Proportional Integral Derivative (PID) control parameters as follows: gain controller K_c = 77 Watt/°C, integral time constant τ_I = 300 second, and derivative time constant τ_D = 75 second. According to the closed loop simulation results, PID Control produced the fastest responses compared to both of P and PI Controls. This study also reveals that by tuning the appropriate control parameters, stable responses can be achieved.

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