SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

PID Control and Overshoot Elimination: Oscillation Curve Simulation

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ARTICLE INFO

Article history:
Received 23 October 2023
Received in revised form 29 December 2023
Accepted 29 January 2024
Available online 19 February 2024

Keywords:

Oscillation curve; PID controller parameters; Overshoot

ABSTRACT

An identification of an industrial process is very necessary. An identification through a mapping chart analysis is conducted to obtain PID control parameters. The parameters of the PID controller are needed to adapt to changes in the process parameters that occur, and at the same time to re-tune the control parameters automatically. This paper discusses a program design that is created to describe the oscillation curve in an industrial process. After the oscillation curve is obtained, then the controller settings: P, PI, PID are tuned. The response curve of the results of the controller settings: P, PI, PID will result in overshoot. Overshoot will be eliminated mainly from the response curve of the results of the PI controller settings.

1. Introduction

The existence of several physical events that change the process characteristics causes the stability of the system to be disrupted, so it is necessary to control the changes in the process parameters. So far, the type of controller that is widely used in the field of industrial control is the PID controller (Proportional, Integral and Differential) [1,2]. The PID controller is actually a conventional controller which, due to its relatively good condition and easy operation, is still widely used. The PID controller provides three kinds of control methods, namely: Proportional (P), Integral (I), Differential (D). In their operation, the three control parameters require good tuning, in order to provide a good and fast output response [3,4].

Many methods have been introduced to tune PID control parameters including the Rungge-Kutta method, however, in an industrial process to get good control performance in each industrial process when overshoot or oscillation occurs, often by the controller operators the control parameters are checked manually through the trial-and-error method. Every change in the process characteristics must be accompanied by a re-tuning of the control parameters [3,5]. The job of retuning the controller is a job that takes time and is very disruptive to the running process. For that we need a technique that is able to adapt to changes in process parameters that occur, and at the same time

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https://doi.org/10.37934/araset.40.1.154163

re-tuning the control parameters automatically. This paper discusses a program to form an oscillation and reduction curve with a PID controller [2,6,7]. The design of this program must at least be in accordance with the dynamics of actual events in the field. The results of this program design are expected to be used for operator training in industrial processes when disturbances occur in the form of oscillations [4.8,9].

2. Literature Study

2.1 Tuning of PID Controller to Create an Oscillation Curve

The K_{pu} critical enhancement and the T_{osc} period that are determined by measurements or calculations[4,6] (see Figure 1).

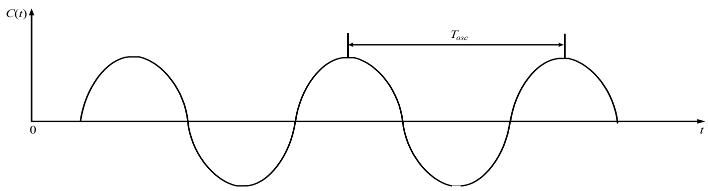

Fig 1. Continuous oscillations of the T_{osc} period

The flow chart for making oscillation curves (heat exchanger data) [7-10] is in Figure 2.

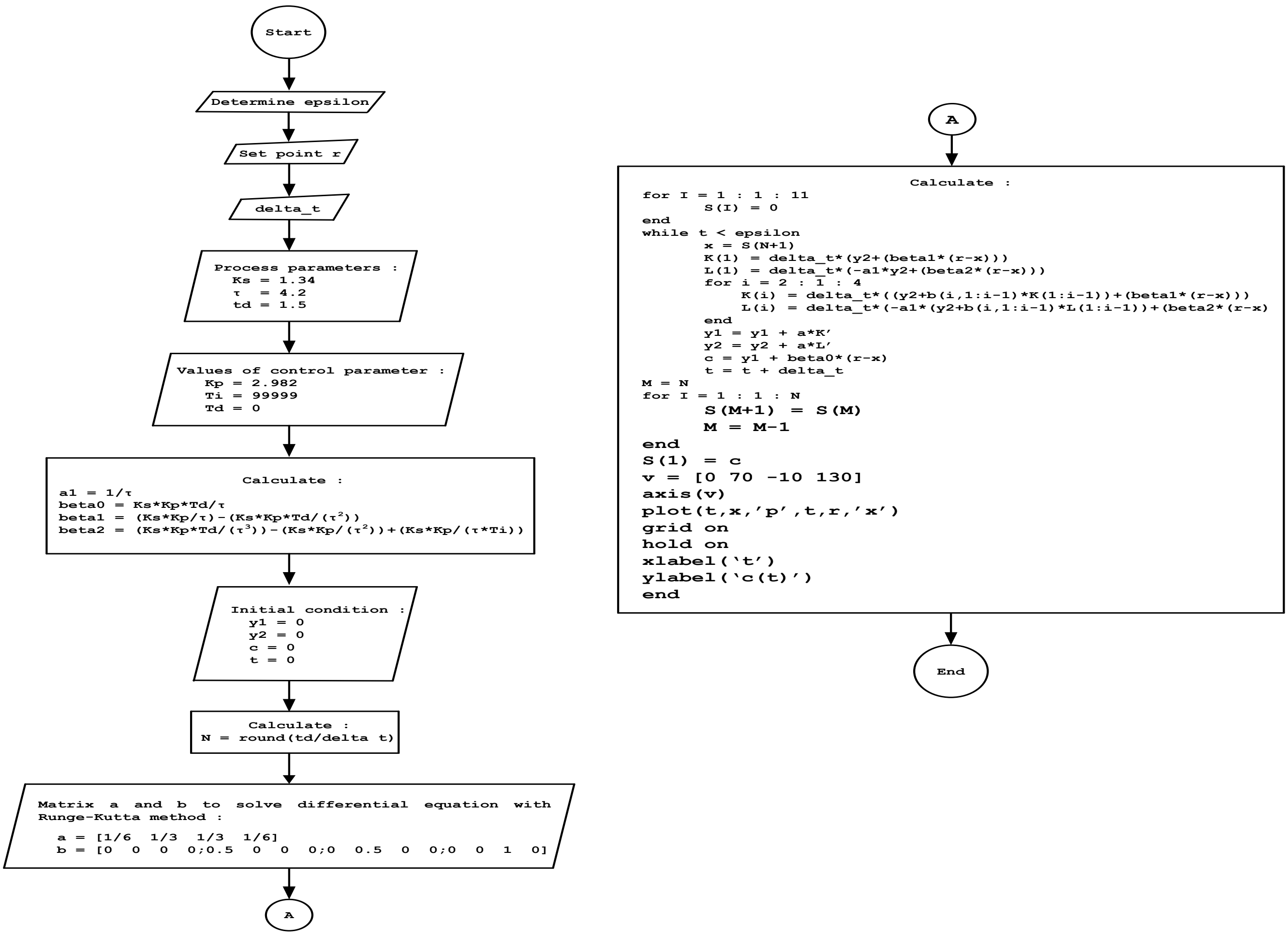

Fig. 2. Flow chart for creating an oscillation curve

2.2 Tuning of PID Controller Oscillation Curve

Zigler and Nichols suggested tuning the parameter values of K_p, T_i, and T_d based on the equation shown in Table 1 [6,10-12].

Table 1
The Ziegler-Nichols tuning rules are based on on the strengthening of K_{pu} and the critical period of $T_{osc\backslash}$

Types of Controllers	K_p	T_i	T_d
P	$0{,}5K_{pu}$	∞	0
PI	$0{,}45K_{pu}$	$\frac{1}{2}T_{osc}$	0
PID	$0{,}6K_{pu}$	$0{,}5T_{osc}$	$0{,}125T_{osc}$

The flow chart for reducing the oscillation curve [13-16] as shown in Figure 3.

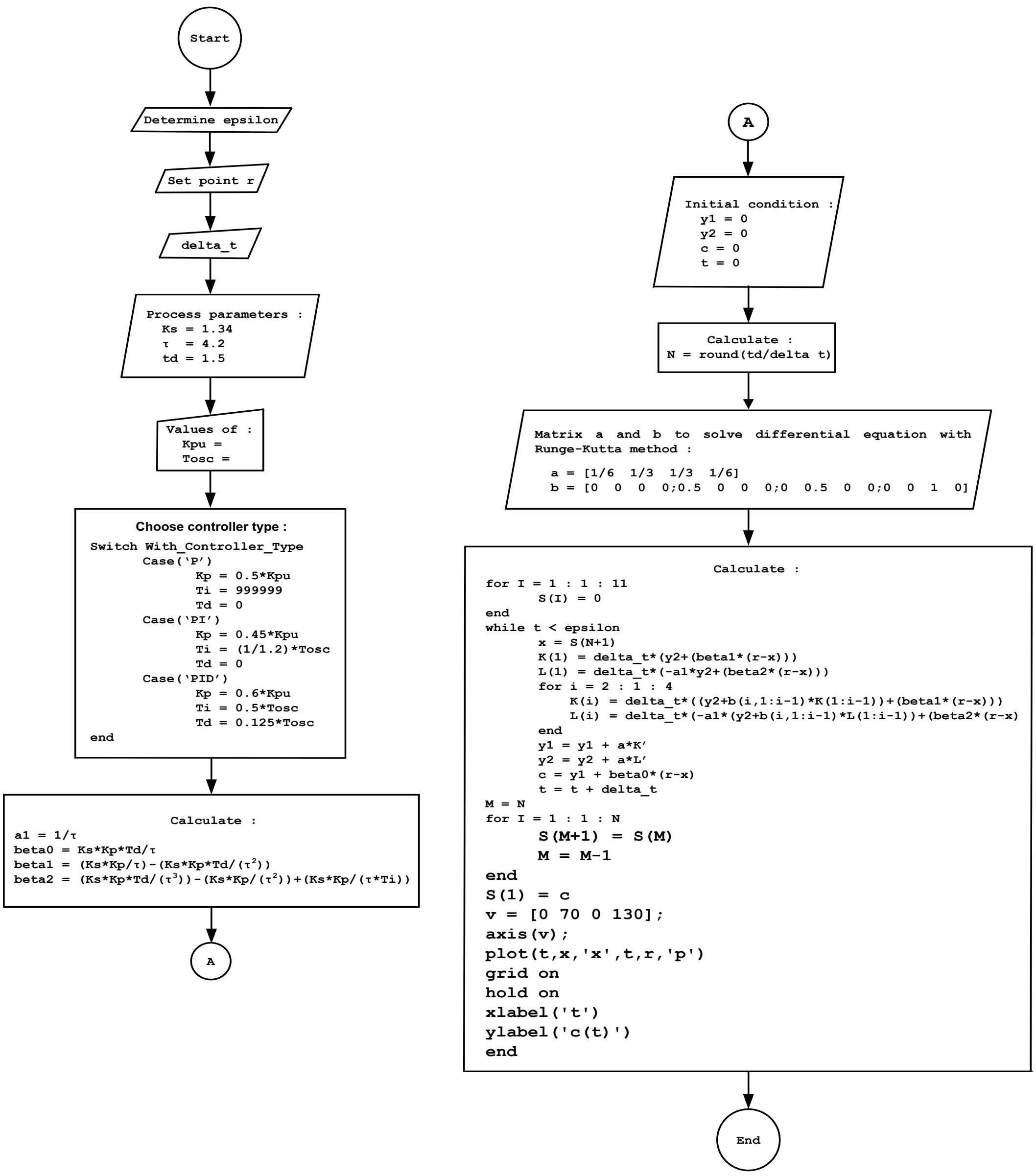

Fig. 3. The program to reduce the oscillation curve

2.3 Elimination of Overshoots

The response curve for a first order system with a time delay that has overshoot that can be eliminated [17-19] by setting the PI controller which can be derived as follows

$$G(s)\,H(s) = K_p\left(1+\frac{1}{T_i s}\right)\left(\frac{K_s}{\tau s+1}e^{-t_d s}\right) \tag{1}$$

with $s = j\omega$, Eq. (1) becomes

$$G(j\omega)H(j\omega) = K_p\left(\frac{j\omega T_i+1}{j\omega T_i}\right)\left(\frac{K_s}{j\omega\tau+1}\right)e^{-j\omega t_d} \tag{2}$$

$T_i = \tau$, is selected, Eq. (2) is obtained

$$G(j\omega)H(j\omega) = \frac{K_p.K_s}{j\omega\tau}e^{-j\omega t_d} \tag{3}$$

The Magnitude of the Eq. (3) is

$$\left|GH\right| = \frac{K_p.K_s}{\omega.\tau} \tag{4}$$

for $w = \omega_c$, the Eq. (4) becomes

$$\left|GH\right| = \frac{K_p.K_s}{\omega_c.\tau} \leq 0{,}5 \tag{5}$$

The angle of the Eq. (5) is

$$\angle GH = -\frac{\pi}{2} - \omega.t_d \tag{6}$$

For $\omega = \omega_c$, the Eq. (6) becomes

$$\angle GH = -\frac{\pi}{2} - \omega_c.t_d \tag{7}$$

The Eq. (7) is made into

$$-\frac{\pi}{2} - \omega_c.t_d = -\pi \tag{8}$$

or

$$\omega_c = \frac{\pi}{2.t_d} \tag{9}$$

so that

$$K_p \leq 0,5.\omega_c.\tau \tag{10}$$

$$K_p \leq 0,5.\frac{\pi}{2}.\frac{\tau}{t_d}.\frac{1}{K_s} \tag{11}$$

$$K_p \leq 0,8.\frac{\tau}{t_d}.\frac{1}{K_s} \tag{12}$$

For controller P

$$K_p \leq \frac{0,5}{K} \tag{13}$$

or

$$K_p < 0,8.\frac{\tau}{t_d}.\frac{1}{K_s} \tag{14}$$

The magnitude of $\left|G(j\omega)H(j\omega)\right|$

$$\left|G(j\omega)H(j\omega)\right| = \frac{K_p.K_s\sqrt{(\omega T_i)^2+1}}{\omega T_i\sqrt{(\omega\tau)^2+1}} \tag{15}$$

The Equation of the Characteristics

$$1 + G(s)H(s) = 0 \tag{16}$$

or

$$1 + K_p\left(1+\frac{1}{T_i s}\right)\left(\frac{K}{\tau_s + 1}\right) = 0 \tag{17}$$

or

$$(T_i s)(\tau s + 1) + K_p.K_s(T_i s + 1) = 0 \tag{18}$$

or

$$T_i \tau s^2 + T_i s(1 + K_p.K_s) + K_p.K_s = 0 \tag{19}$$

with *GB* = *Kp.Ks* and so that the system does not give oscillations, then out of the Eq. (19) is obtained

$$T_i^2(1+K_p.K_s)^2 - 4T_i.\tau.K_pK_s \geq 0 \quad (20)$$

or

$$T_i \geq \frac{4\tau\, GB}{(1+GB)^2} \quad (21)$$

Figure 4 shows the relationship between *GB* and T_i as the border between the oscillating and non-oscillating systems.

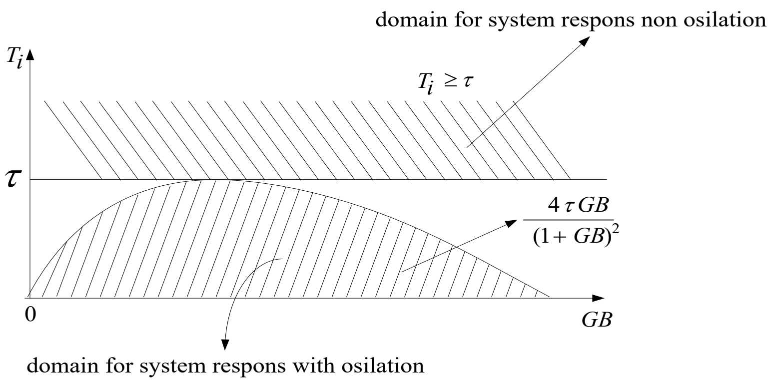

Fig. 4. The relationship between GB and T_i the border between oscillating and non-oscillating systems

3. Results and Analysis
3.1 Results

The results of a program to describe a continuous oscillation curve on a heat exchanger with data as follows: K_s = 1.34, τ = 4.2, t_d = 1.5 minutes and prices: epsilon = 70.01, r = 70, delta_t = 0.2, and K_{pu} = 2.982 as shown in Figure 5 below.

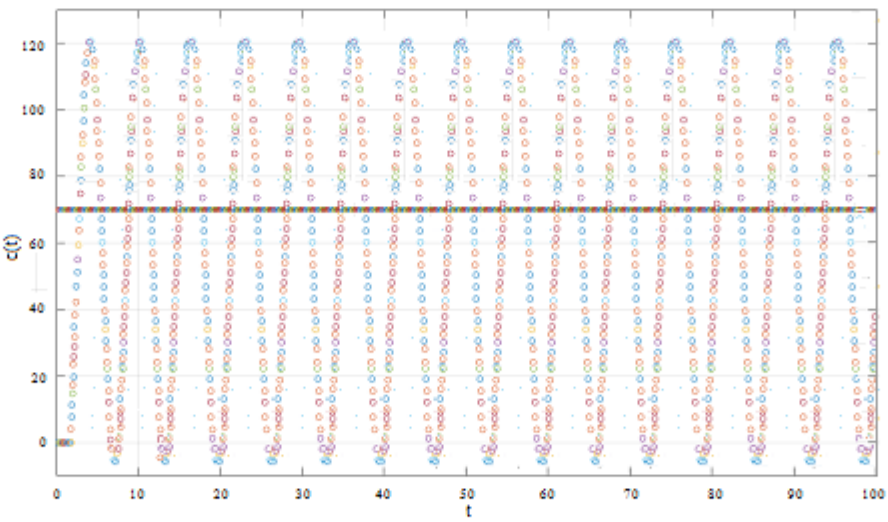

Fig. 5. The results of a continuous oscillation response curve program

The tuning of PID controller of the continuous oscillation response curve in Figure 5 above with the values: epsilon = 70.01, r = 70, delta_t = 0.2, K_{pu} = 2.982, T_{osc} = 6 minutes, and the controller tuning types selected are 'P', 'PI' , and 'PID'. Based on Table 2, it can be determined for the controller settings:

- With the type of P

K_p = 0,5 . K_{pu} = 0,5 . 2,982 = 1,491
$T_i = \infty$
T_d = 0

- With the type of PI

K_p = 0,45 . K_{pu} = 0,45 . 2,982 = 1,3419

$$T_i = \frac{1}{1{,}2} T_{osi} = \frac{1}{1{,}2} \times 6 = 5$$

T_d = 0

- With the type of PID

K_p = 0,6 . K_{pu} = 0,6 . 2,982 = 1,7892
T_i = 0,5 .T_{osi} = 0,5 . 6 = 3
T_d = 0,125 . T_{osi} = 0,125 . 6 = 0,75

The results of the tuning type of the 'P' controller are shown in Figure 6, for the 'PI' controller type as shown in Figure 7, and for the 'PID' controller type as shown in Figure 8.

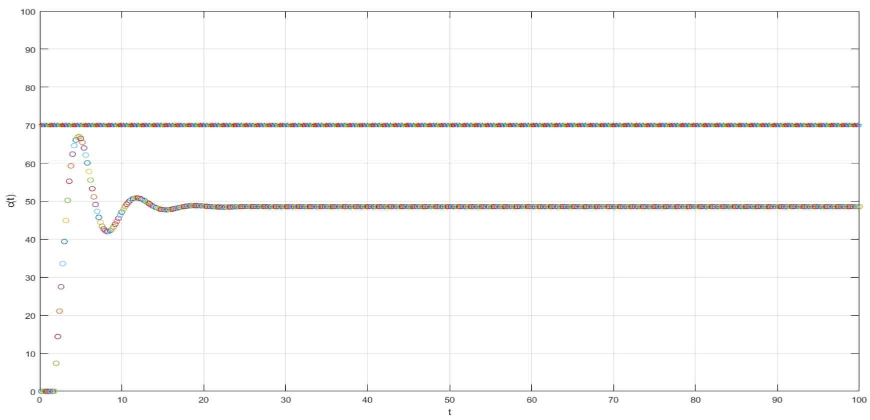

Fig. 6. The tuning of continuous oscillation response curve of Figure 5 for the controller type of 'P'

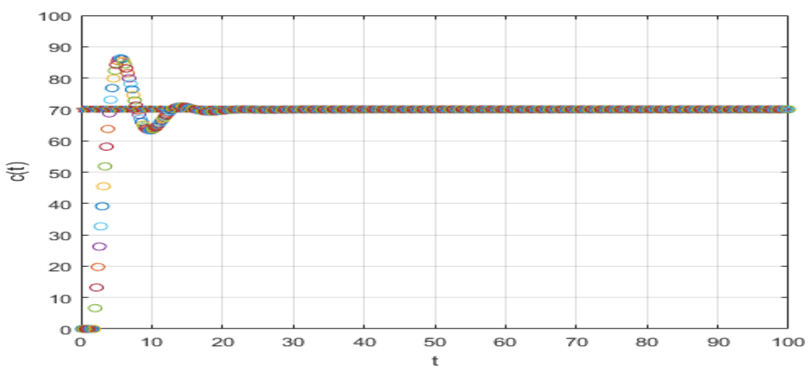

Fig. 7. The tuning of continuous oscillation response curve of Figure 5 for the controller type of 'PI'

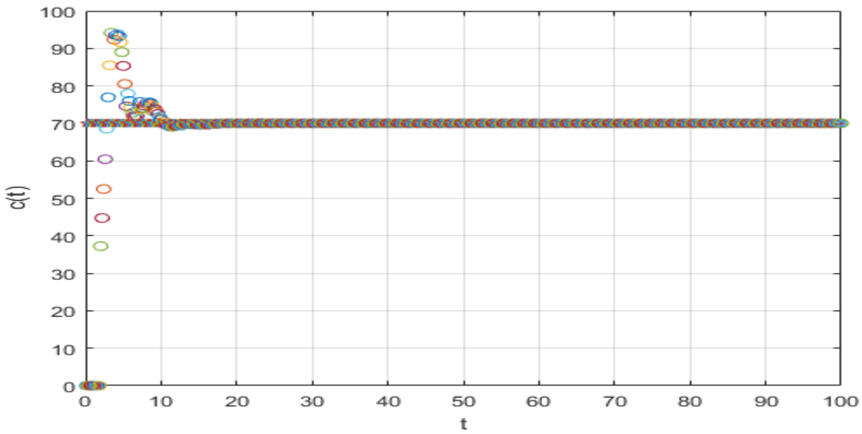

Fig. 8. The tuning of continuous oscillation response curve of Figure 5 for the controller type of 'PID'

The elimination of overshoot in Figure 7 is by determining the magnitudes of K_p, T_i and for T_d = 0. To determine K_p and T_i is by using Eq. (13) and Eq. (21). In which the price of the static amplifier K = 1.34, τ = 4.2 minutes. So that the value of K_p is as follows:

$$K_p \leq \frac{0{,}5}{K}$$
$$K_p \leq \frac{0{,}5}{1{,}34}$$
$$K_p \leq 0{,}373$$

For the value of K_p the value of K_p = 0,3 is taken. The value of T_i can be sought as follows:

$$T_i \geq \frac{4\tau.K_p.K}{(1+K_p.K)^2}$$

By inputting the above values, then

$$T_i \geq \frac{4\ .\ 4{,}2\ .\ 0{,}3\ .\ 1{,}34}{(1+\ 0{,}3\ .\ 1{,}34)^2}$$
$$T_i \geq 3{,}436$$

Or

$$3{,}436 \leq T_i$$

For the value of $T_{i,}$ T_i = 3,5 minutes can be used. So for the simulation, the value of K_p = 0.3, T_i = 3.5 minutes, and T_d = 0. So that Figure 7 eliminates the overshoot, and the results are as shown in Figure 9.

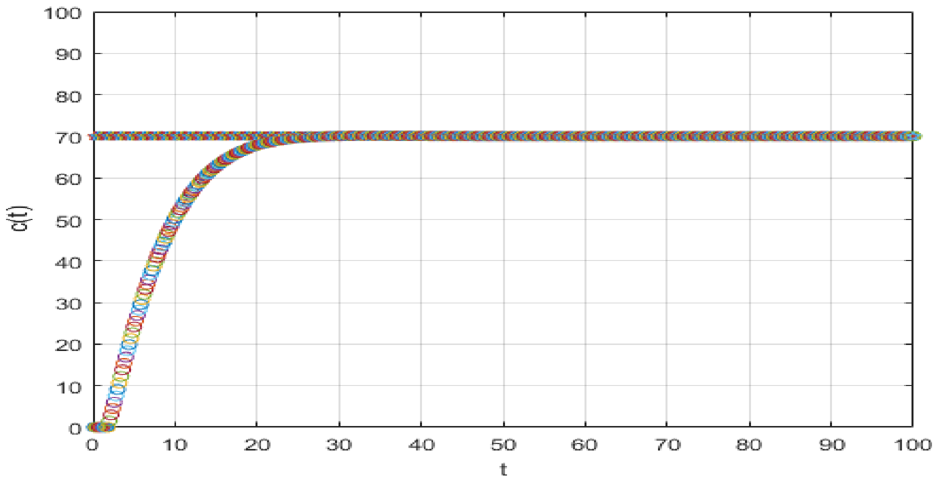

Fig. 9. Response curve after being eliminated from Figure 7

3.2 Analysis

The results of the program design to produce a continuous oscillation curve on a heat exchanger with the data of K_s = 1.34, τ = 4.2, t_d = 1.5 minutes and the values of: epsilon = 70.01, r = 70, delta_t = 0.2, and K_{pu} = 2.982, T_{osc} = 6 minutes as shown in Figure 5. From the oscillation curve of Figure 5 then the tuning of the P controller response curve is as shown in Figure 6, the tuning of the PI controller response curve is as shown in Figure 7, the tuning of the PID controller response curve is as shown in Figure 8. The Peak of Overshoot of the tuning results of the PI controller is as shown in Figure 7 which is at a time of tp = 3.80 minutes with c(tp) = 86.36°C, so that the percent of overshoot is $Mp = \left(\frac{86,36 - 70}{70}\right) \times 100\% = 23,37\,\%$. The result after eliminating the overshoot is as shown in Figure 9.

4. Conclusion

To produce an oscillation curve on a heat exchanger with a critical enhancement of K_{pu} = 2.982 and a period of T_{osc} = 6 minutes. The overshoot that occurs in the PI controller tuning, the response curve is at time tp = 3.80 minutes with c(tp) = 86.36°C, so that the percent of overshoot is Mp = 23.37%. After being eliminated there is no more overshoot.

Acknowledgement
Thank you to the Rector of the University of Muhammadiyah Palembang for the encouragement and financial assistance for the publication of this article.

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