

Study on the Effect of Time Constant on Flow and Temperature Controllability

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Abstract— In this research paper, the objectives are to determine which parameters show the fast response time constant upon the process based on the time constant method which is numerical analysis. Besides that, in order to observe which parameters give the fast response, it is required to perform the performance test and observe the settling time for each method. Tangent analysis is a conventional method used to analyzed an open loop step response curve. It is done by drawing a tangent line at the steepest point of the step response curve. In this research project, numerical analysis is used as it is much faster in obtaining data compared to the conventional tangent analysis. The process dynamics such as dead time and response rate can be obtained from the analysis. Meanwhile, values of the response rate, RR, and the dead time, T_d , differs comparing flow and temperature, which in turn, resulted in different values of P's and I's of different tuning method which are Ziegler-Nichols, Cohen Coon and Takahashi.

Keywords— Controller tuning, Cohen Coon, step response, system identification, numerical analysis, Takahashi, Ziegler-Nichols.

I. INTRODUCTION

Process control refers to the ways methods that are used to regulate process variables when manufacturing a product [1]. Factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product. Maintaining process variables such as pressure, flow, level, temperature, and pH within a desired operating range is of the utmost importance when manufacturing products with a predictable composition and quality.

In general terms, the time constant, T_c , describes how fast the PV moves in response to a change in the MV. The time constant must be positive and it must have units of time. For controllers used on processes involved of gases, liquids, powders, slurries and melts, T_c most often has units of minutes or seconds.

This research project is to study on the effect of time constant on the flow controllability. This can be achieved by doing an open loop test, followed by the performance test using three different tuning rules, which are Ziegler-Nichols, Cohen Coon and Takahashi.

In a processing plant, it is very important to determine the most optimum algorithm values (P, I and D) for the controller's settings, which are also known as PID tuning. This is as the PID tuning will influence on how fast the controller's response in order to perform a corrective action during the presence of step or load disturbance in a particular process. .

Generally, flow control loops are regarded as fast loops that respond to changes quickly. Therefore, flow control equipment must

have fast sampling and response times. Because flow transmitters tend to be rather sensitive devices, they can produce rapid fluctuations or noise in the control signal [1]. Figure 2.3 shows the typical control loop for flow.

Temperature is a very critical and widely measured variable for most mechanical engineers. Many methods must have either a monitored or controlled temperature. This can range from the simple monitoring of the water temperature of an engine or load device, or as complex as the temperature of a weld in a laser welding application [2].

II. DISCRETE TANGENT METHOD

This method is the most latest advancement in computing technology, that allows data to be collected and recorded numerically [3]. By using distributed control system (DCS), supervisory control and data acquisition (SCADA) and paperless recorder, the data can be collected in an open loop response process [4]

The formula for calculating each parameters are as follow:

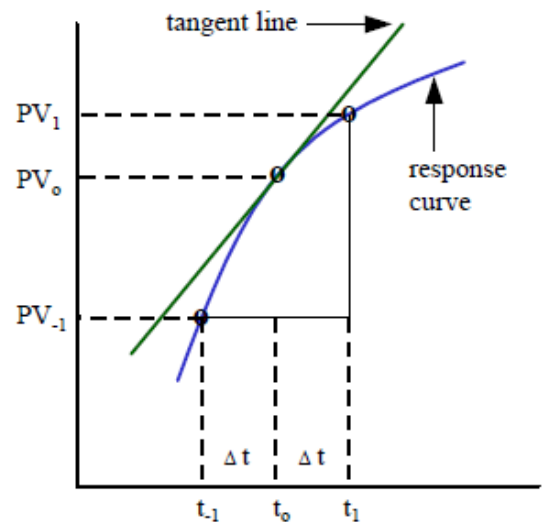


Fig. 1: The numerical method [3]

Response rate, RR

$$RR = \frac{PV_1 - PV_{-1}}{2\Delta h \Delta MV} \quad \dots \dots \dots (1)$$

Dead time, T_d

$$T_d = t_1 - 2\Delta h \frac{PV_1 - PV_i}{PV_1 - PV_{-1}} \quad \dots \dots \dots (2)$$

Time constant, T_c

$$T_c = 2\Delta h \frac{PV_f - PV_i}{PV_1 - PV_{-1}} \quad \dots \dots (3)$$

III. PID CONTROLLER & TUNING METHOD

The ideal version of the PID controller is followed by the formula:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de}{dt} \quad \dots \dots (4)$$

Where u is the signal of control and e is the control error ($e = r - y$). The reference value, r is also called the set point. The controller parameters are proportional gain k_p , integral gain k_i and derivative gain, k_d . There terms are the sums showing the control signal properties consisting of a proportional term that is proportional to the error, an integral term that is proportional to the integral of the error, and a derivative term that is proportional to the derivative of the error [5].

There are several equations of PID control algorithm. The equations are shown as follow:

$$MV = \frac{100}{P} \left\{ e + \frac{1}{I} \int e dt + D \frac{de}{dt} \right\} \quad \dots \dots (5)$$

$$MV = \frac{100}{P} e + \frac{1}{I} \int e dt + D \frac{dPV}{dt} \quad \dots \dots (6)$$

$$MV = Kc \left\{ e + \frac{1}{I} \int e dt - D \frac{dPV}{dt} \right\} \quad \dots \dots (7)$$

These characteristics of PID controller are the tendency to produce overshoot, undershoot, off-set and oscillation in the system response. The selection of P, I, and D values is very important. They determine whether the process is oscillatory, stable or unstable. To obtain a stable process, numerous combinations of P, I and D values are possible, but there is only one combination that will produce an optimum response curve [6].

Table 1, 2 and 3 shows the tuning method that are used in this research project for tuning purposes. The tunings method are Ziegler-Nichols, Cohen Coon and Takahashi Methods.

Table 1: Tuning Of PID Controller Parameters According To Ziegler-Nichols Method [4]

Mode	P	I	D
P	100 RR Td		
P I	111.1 RR Td	3.33 Td	
P I D	83.3 RR Td	2 Td	0.5 Td

Table 2: Tuning Of PID Controller Parameters According To Cohen Coon Method [4]

Mode	P	I	D
P	$\frac{100}{1 + \frac{\mu}{3}} RRT_d$		
P I	$\frac{100}{1 + \frac{\mu}{11}} RRT_d$	$3.33 \left[\frac{1 + \frac{\mu}{11}}{1 + \frac{11\mu}{5}} \right] T_d$	
P I D	$\frac{100}{1.35 \left(1 + \frac{\mu}{5} \right)} RRT_d$	$2.5 \left[\frac{1 + \frac{\mu}{5}}{1 + \frac{3\mu}{5}} \right] T_d$	$\frac{0.37 T_d}{1 + \frac{\mu}{5}}$

Table 3: Tuning Of PID Controller Parameters According To Takahashi Method [4]

Mode	P	I	D
P	100 RR Td		
P I	111.1 RR Td	3.33 Td	
P I D	83.3 RR Td	2 Td	0.5 Td

IV. METHODOLOGY

A. Open Loop Analysis

In order to find which method gives the best and fast response to the system. Open loop test will be carried out

1) Open loop test

In this research project, the experiment is done by numerical Analysis using DCS FOXBORO. In order to run the open loop test, Numerical Discrete Method is done. These tests are done for flow using the system FIC 91 and temperature using TIC 92.

In this research work, discrete method is used as it is the advanced technology. From the open loop test, the value that is obtained are such Response Rate (RR), Dead Time (Td) and Time Constant (Tc). These values will be used in Tuning Rule to get the optimum P, I & D. Open Loop test must be carried out in MAN mode.

A step change is made between 5% to 20% to the manipulated variable. In order to determine the PI Controller, Ziegler Nichols, Cohen Coon and Takahashi methods will be used in order to see which tuning gives a better response to the changes.

B. Closed Loop Test

Closed loop test consist of the performance test which are the load disturbance test and set point test. After getting the value of the PI Controller, the tuning will be carried out if the response oscillates.

1) Load Disturbance Test

The controller is set to be in manual mode. MV is changed of about 10% of current MV Value and response is observed until stable.

2) Set Point Test

The controller is set to be in automatic mode. The set point is changed of about 10% of current operating process value and response is observed until stable.

V. RESULTS AND DISCUSSION

A. Flow controllability using FIC 91

In this experiment, to run the open loop test, a numerical analysis is being done for both flow and temperature process. Numerical analysis is done by using FOXBORO. The data obtained is tabulated as follow for both flow (FIC 91) and temperature (TIC 91) process.

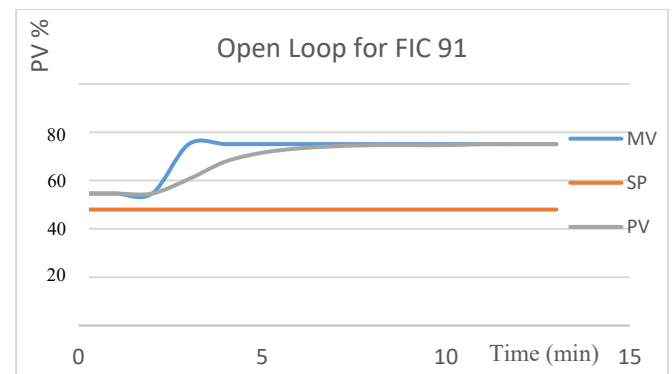


Fig. 2: The Open Loop Test for FIC 91

Figure 2 shows the response curve from the open loop test. From the open loop test, the values of RR, T_c and T_d can be calculated and the values are tabulated in Table 4. The values consists of both of the parameters which are flow and temperature as comparison.

From the data obtained and calculated from the open loop test, it is used in tuning rules method of Ziegler Nichols, Cohen Coon, and Takahashi in order to compare the performance test. The value of the calculated P, I and D is tabulated in Table 5 for flow process.

Table 4: Comparison between Flow and Temperature Process

Properties	FIC 91	TIC 92
RR	0.303	0.0013
T _c	3.089 s	26.36 min
T _d	2 s	34.08 min

Based on the observation from Table 5, for a process which has the dead time to be longer than the time constant, the process is reasonably easy to tune. This can be seen by the flow process, where it needs only one time tuning for each tuning method for the process to become stable for any changes to the manipulated variable. Unlike flow, for temperature based process, the time constant is shorter than the dead time, therefore, it needs to be tuned more for it to become stable to any changes that is made.

Table 5: Values of P and I for Flow Process

Ziegler Nichols		
Mode	P	I
PI	67.1044	0.111
Cohen Coon		
Mode	P	I
PI	57.04	0.04848
Takahashi		
Mode	P	I
PI	66.44	0.11

Step performance test is done in order to see how the performance of the tuning rule applied for the process. There are two tests which are load disturbance and set point test. The first performance test is to increase the load (MV) to 10%, thus the curve is observed. The second test is the set point test, which the set point is set to increase 10-20% of its original value. For example, the manipulative variable is increased from 63% to 73%, and later, the set point is increase from 2 to 2.3 m³/h.

Comparing the 3 tuning rules, it shows that Cohen Coon method gives faster response compared to Ziegler-Nichols and Takahashi method as observed in Figure 3. The response shows it overshoots, and stable after a minute average.

For load disturbance test, Ziegler-Nichols shows slow response compared to Takahashi method, but somehow very similar time taken for the response to be constant. Both of Cohen Coon, and Takahashi overshoot when set point test is being done, but Cohen Coon gives faster response to become constant and steady, thus the time constant of Cohen Coon is faster than Takahashi.

Unlike Ziegler and Takahashi, the process response curve when load disturbance test is done, Cohen Coon type of response curve shows it is overdamped. Overall, the curves are all overdamped type as shown in the graphs. As for flow process, it can be concluded that

Cohen Coon gives a better response to any disturbance thus it has the fastest time constant to be compared with Ziegler Nichols and Takahashi. The type of response, time constant and the settling time taken for any disturbance is tabulated in Table 8 at the end of the discussion as summary of the results.

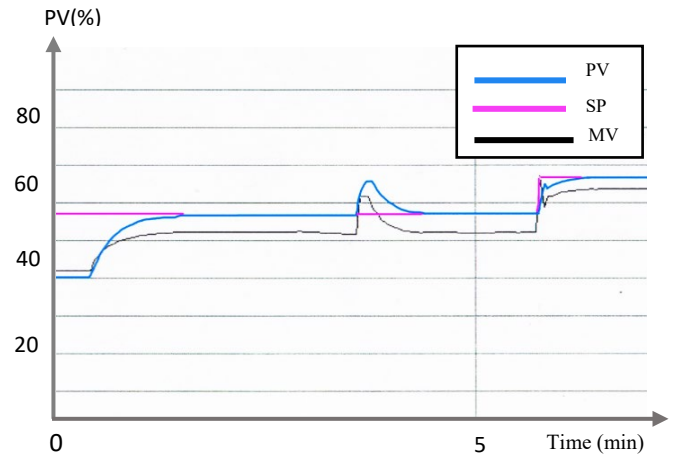


Fig. 3: Close loop test, load disturbance test and set point test using Ziegler-Nichols Tuning

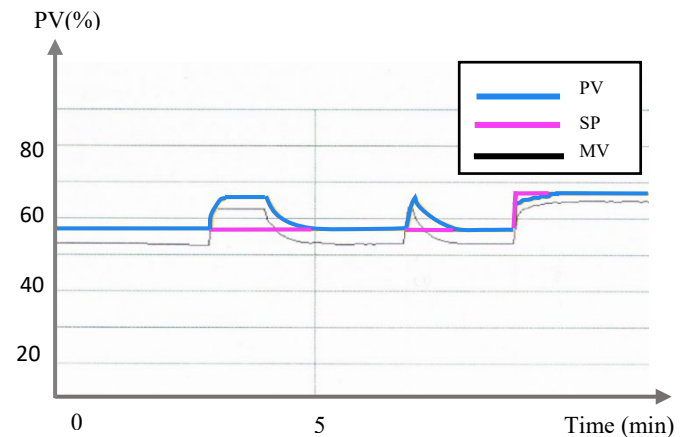


Fig. 4: Close loop test, load disturbance test and set point test using Takahashi Tuning

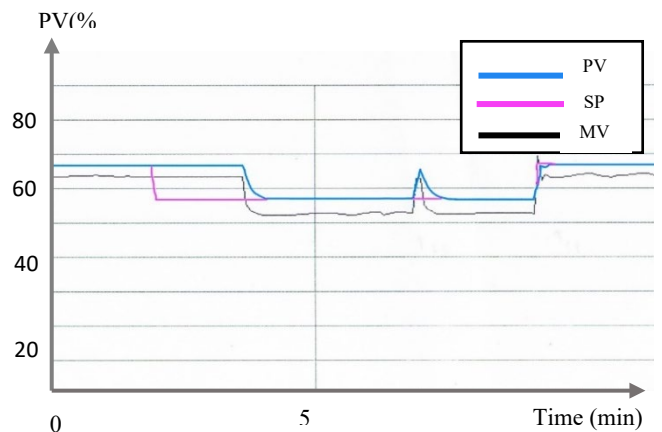


Fig. 5: Close loop test, load disturbance test and set point test using Cohen Coon Tuning

B. Temperature controllability using TIC 92

As for TIC 92, the results shown the process took longer time for it become constant as it is known than temperature is a slow response process. Unlike flow, for temperature based process, the time constant is shorter than the dead time, therefore, it needs to be tuned more for it to become stable to any changes that is made. The whole

process on getting the values of time constant in open loop test is longer and time consuming compared to flow process.

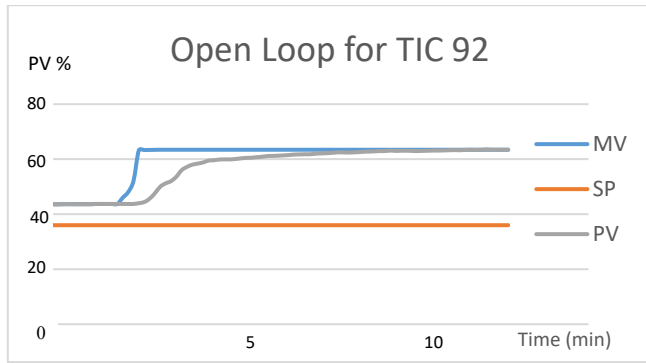


Fig. 6: The Open Loop Test Response Curve for TIC 92

As mentioned earlier, the time constant is 25.26 minutes and the dead time is 34.09 minutes. Meanwhile, the response rate, RR is 0.0013. From the data obtained from the open loop test, it is used in tuning rules method of Ziegler Nichols, Cohen Coon, and Takahashi in order to compare the performance test. The value of the calculated P, I and D is tabulated in Table 4.4 for temperature process

Table 6: The Value of PID for Temperature Process

Ziegler Nichols			
Mode	P	I	D
P I D	128.23	68.42	17.10
Cohen Coon			
Mode	P	I	D
PID	90.53	60.56	10.05
Takahashi			
Mode	P	I	D
PID	118.53	75.26	15.39

Figure 7 shows the first tuning using the PID value calculated for Ziegler-Nichols and it shows that the response curve oscillate and have high robustness.

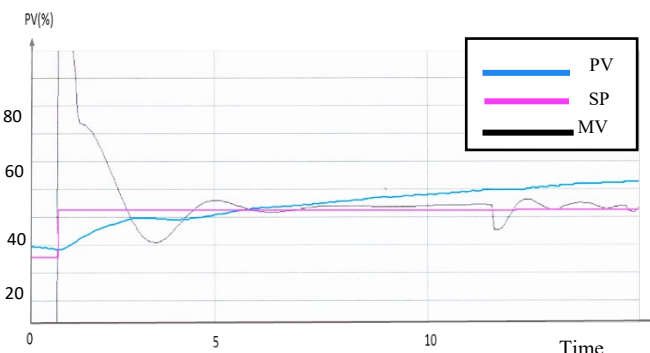


Fig. 7: First tuning of temperature control using Ziegler-Nichols rules.

In order to get the stable process curve, a fine tuning is done. The value of P, I and D is divided into 4 and 2 as for temperature gives unsteady and high robustness in the process span. But however, the graph shows the process is unstable if the value of P is tuned as well. Therefore, the final tuning is done for values I and D as it gives better stability to the process flow. The final tuning value is shown in Table 4.5. After the second tuning, based on Figure 8 the process response curve shows it is approaching to

the set point at the end of the graph and shows it is stable towards the end.

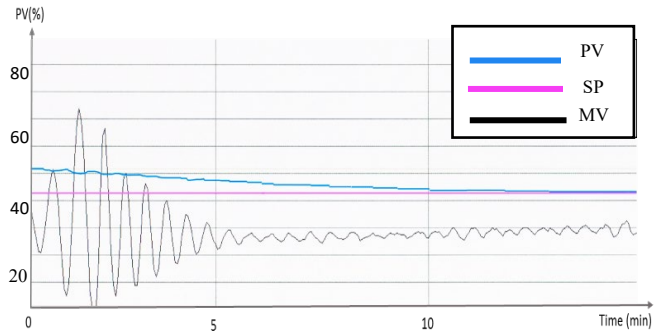


Figure 8: Fine tuning using Ziegler-Nichols rules

Table 7: Summary of fine Tuning Value for Temperature Process

Ziegler Nichols			
Mode	P	I	D
P I D	128.223	68.417	17.104
PID (1st Tuning)	32.056	17.104	4.276
PID (2nd Tuning)	32.056	8.552	2.138
Cohen Coon			
Mode	P	I	D
PID	90.535	60.565	10.049
PID (1st Tuning)	22.634	15.141	2.512
PID (2nd Tuning)	11.316	7.571	1.256
Takahashi			
Mode	P	I	D
PID	118.532	75.258	15.394
PID (1st Tuning)	29.633	18.815	3.848
PID (2nd Tuning)	14.816	9.407	1.924
PID (3rd Tuning)	14.816	4.704	0.962

For the first tuning using Ziegler Nichols, it took roughly around 20 minutes for it to become constant but however it does not reach the set point. After some fine tuning, it took for about another roughly 20 minutes for it to become constant and reach the set point. Meanwhile, for Cohen Coon, the time taken for the process to be stable is much faster compared to Ziegler Nichols. Figure 9 and 10 shows the fine tuning and performance test using Cohen Coon.

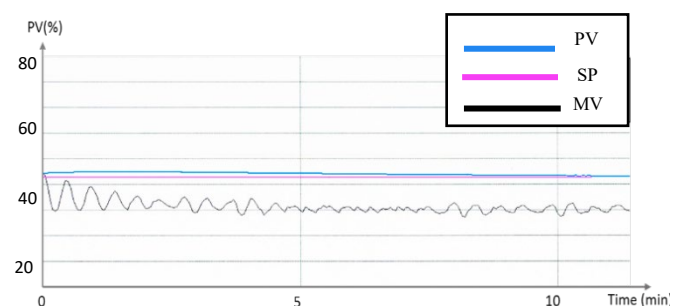


Fig. 9: Fine Tuning using Cohen Coon Rules

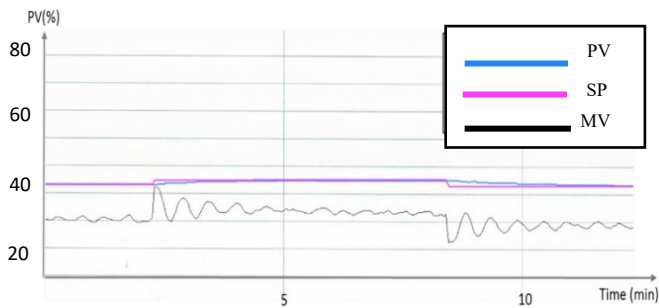


Fig. 10: Load Disturbance and set point test using Cohen Coon Rules

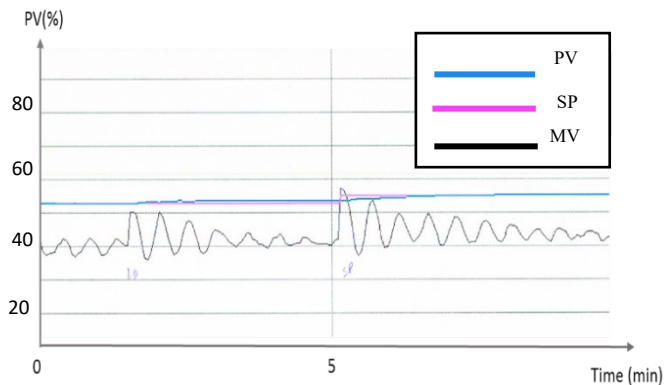


Fig. 11: Load Disturbance and Set Point Test Using Takahashi Rules

However, for temperature process, it is observed that Takahashi gives better tuning response than both Ziegler Nichols and Cohen Coon in both of the performance tests, load disturbance and set point tests. This can be seen by in Figure 11, where the response curve shows that the time taken for it to be constant is as faster and the settling time is also short. This could be reason because the value of integral for Takahashi is the smallest of all tuning.

Table 8 and 9 shows the summary of flow and temperature, respectively of the parameters tested in terms of their time constant, settling time and their type of response curve

Table 8: Summary Of Parameters Obtained From Performance Test On Flow Process

Ziegler Nichols			
Type of Test	Time Constant (s)	Settling Time (s)	Type of Response Curve
Load Disturbance	20	46	Underdamped
Set Point	12	29	Overdamped
Cohen Coon			
Type of Test	Time Constant (s)	Settling Time (s)	Type of Response Curve
Load Disturbance	11	20	Overdamped
Set Point	9	14	Overdamped
Takahashi			
Type of Test	Time Constant (s)	Settling Time (s)	Type of Response Curve
Load Disturbance	16	37.8	Underdamped
Set Point	11	29.4	Overdamped

Table 9: Summary of Parameters Obtained From Performance Test on Temperature Process

D			
Type of Test	Time Constant (min)	Settling Time (min)	Type of Response Curve
Load Disturbance	3.6	5.1	Underdamped
Set Point	2.4	4.3	Overdamped
Cohen Coon			
Type of Test	Time Constant (min)	Settling Time (min)	Type of Response Curve
Load Disturbance	2.9	3.7	Underdamped
Set Point	1.8	2.6	Overdamped
Takahashi			
Type of Test	Time Constant (min)	Settling Time (min)	Type of Response Curve
Load Disturbance	1.13	1.55	Underdamped
Set Point	1.3	1.85	Overdamped

VI. CONCLUSION

This research project is on determination the effect of time constant to the flow and temperature controllability of where flow is a fast response, while temperature is a slow response process. From the data that obtained, and from the performance tests that has been done, it shows that for fast response flow process it is easier to tune, as the time constant is longer than the dead time. Thus, there is not much of tuning needed. Meanwhile, for temperature process, in order for the response to become stable, it needs to be tuned accordingly until it gives a stable response and reached set point. In terms of performance test, it shows that Cohen Coon shows the best response for flow process. Meanwhile, Takahashi gives the best response to the changes to temperature process.

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