Study on the Optimum Pressure Controllability of PID Tuning by Using Different Tuning Rules

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***Abstract*— This study is carried out to determine the optimum pressure controllability by using various tuning rule. There are several analyses conducted in this study which are open loop analysis and closed loop analysis. The method used for open loop test is Reformulated Tangent Method while the different tuning rules used is Ziegler-Nichols; Cohen-Coon; Chien, Hrones and Reswick (CHR) and Takahashi. Next, closed loop analysis is carried out by performing performance tests and fine tuning. This performance tests are conducted to observe and investigate the best and efficient tuning rule when the set point and load disturbance is change [1]. The controller that has minimum settling time and peak overshoot and less error will be considered as the best controller and efficient controller [4].**

***Keywords*— Load Disturbance Test, Tuning Rules, Pressure control, Set Point Test**

I. INTRODUCTION

In process control industry, the PID tuning is used to adjust the controller parameters in order to obtain a result in a good closed-loop behavior. This is due to the impact of PID tuning on how fast the controller will respond to do a corrective action during the regulatory control. In order to fulfil this, the tuning rules is used to obtain the optimum P, I and D value. However, the best and effective method is not obtained in order to get the best process response for the pressure control. Thus, in order to overcome this issue, this research is conducted to determine the optimum pressure controllability by using various tuning rules.

Process control is a method that are used in this study to control process variables in order to regulate the value of some quantity to maintain the quantity at some desired value regardless of external influences.

Process control loop is comprising of four control blocks which are controller, final control element, process and sensor [1]. An instrument called a sensor is added to measure the value of the level and convert it into a proportional signal [6]. This signal is provided as an input to a machine, electronic circuit, or computer that called as a controller. The controller performs the function of the operator in estimating the measurement and providing an output signal to change the valve setting by using an actuator that connected to the valve by a mechanical linkage [6]. Final control element is an electro-mechanical device such as control valve that translates the corrective action into mechanical-equivalent action [1].

Besides that, PID tuning is used to obtain the value of P, I and D value. PID tuning is the process of adjustment of the controller parameters to obtain a specified closed loop response [1]. In order to obtain the final optimum P, I and D, the calculated optimum P, I and D is tested for the actual performance in handling a change in set point and a change in process loading of load variable [1].

The objectives of this study are to determine the optimum pressure controllability by using five different tuning rules and to compare the performance of the tuning rule thus predict the most efficient PID controller tuning for pressure process.

II. METHODOLOGY

A. Reformulated Tangent Method

The open loop test is performed by using reformulated tangent method. It is done by setting the controller's output in manual mode and making a load change which is manipulated variable (ΔMV) of 5 to 20% [2]. The outcome of the response curve is recorded until it reaches a steady state in order to perform an analysis [5]. Moreover, the response curve is analyzing for the process characteristics which is response rate (RR), dead time (T_d) and time constant (T_c) as in Equation (1), (2) and (3).

Response rate (RR):

$$RR = \frac{\tan\theta}{\Delta MV}\frac{a}{b} \quad \text{… … … … …} (1)$$

Dead time (T_d):

$$T_d(time) = T_d(length) \times b \quad \text{… … … … …} (2)$$

Time constant (T_c):

$$T_c(time) = T_c(length) \times b \quad \text{… … … … …} (3)$$

Where,
RR = response rate, 1 / time
a = scaling factor for y-axis, % / length
b = scaling factor for x-axis, time / length
ΔMV = change in controller's output, %

B. Tuning Rules by Ziegler-Nichols

Ziegler-Nichols was presented in 1940s. The methods are the most popular methods used in process control to determine the parameters of a PID controller and widely used until now [2]. The Table 1 shows the PID controller parameters by Ziegler-Nichols.

Table 1: Tuning Rules by Ziegler-Nichols

Mode	P	I	D
P	100 RR T_d		
PI	111.1 RR T_d	3.33 T_d	
PID	83.3 RR T_d	2 T_d	0.5 T_d

C. Tuning Rules by Cohen-Coon Method

The Cohen-Coon tuning rules is a more complex version of the Ziegler-Nichols method [2]. However, Cohen-Coon method work well on all self-regulating and fast response process. Table 2 shows the controller parameters of Cohen-Coon tuning rules.

Table 2: Tuning Rules by Cohen-Coon Method

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

Where, $\mu = \frac{T_d}{T_c}$

D. Tuning Rules by Chien, Hrones & Reswick (CHR)

Tuning rules method that proposed by Chien, Hrones and Reswich (CHR) is a modification of open loop Ziegler and Nichols method [3]. They proposed to use “quickest response without overshoot” or “quickest response with 20% overshoot” as design criterion [3]. Table 3 and 4 shows the controller parameters for 0% overshoot and 20% overshoot of CHR tuning rules.

Table 3: Tuning Rules by Chien, Hrones & Reswick (CHR) (0% overshoot)

Mode	P	I	D
P	333 RR T_d		
PI	286 RR T_d	1.2 T_d	
PID	167 RR T_d	T_d	0.5 T_d

Table 4: Tuning Rules by Chien, Hrones & Reswick (CHR) (20% overshoot)

Mode	P	I	D
P	143 RR T_d		
PI	167 RR T_d	T_d	
PID	105 RR T_d	1.35 T_d	0.47 T_d

E. Tuning Rules by Takahashi

Takahashi also developed the similar relations to calculate the controller parameters. The Table 5 shows the formula to calculate the optimum P, I and D value using tuning rules by Takahashi.

Table 5: Tuning Rules by Takahashi

Mode	P	I	D
P	110 RR T_d		
PI	110 RR T_d	3.3 T_d	
PID	77 RR T_d	2.2 T_d	0.45 T_d

III. RESULTS AND DISCUSSION

A. Open Loop Analysis

During an open loop test, the 10% step change is made to the manipulated variable, which is from 55% to 65%. After the steady state was achieved, the response curve was analyzed as shown in Figure 6. The scaling factors (a, b) are calculated to balance up the response rate (RR), dead time (T_d) and time constant (T_c) values. In this study, the scaling factor a and b is 0.588 %/mm and 1.304 s/mm. By using Equation (1), (2) and (3); RR, T_d, and T_c was obtained which is 0.09246 /s, 3.912 s and 22.168s.

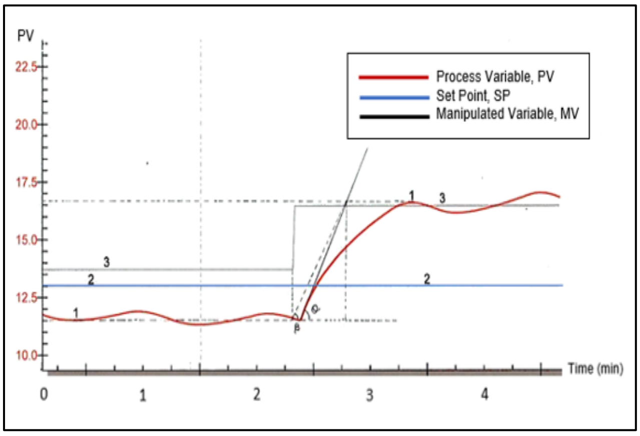


Fig 1. Open Loop Response

Moreover, there are five different tuning rules was used which is Ziegler-Nichols (Z-N), Cohen-Coon (C-C), Chien, Hrones & Reswick (CHR) and Takahashi. Besides that, pressure control is one of the type of fast process response and noisy process. Thus, the P+I mode of control is used, which only the proportional (P) and Integral (I). The value of proportional (P) and Integral (I) calculated from the tuning rule as shown in Table 1,2,3,4 and 5 is applied to the response for each tuning method. However, the value of calculated P and I that was introduced to the process makes the process becomes oscillated for all types of tuning methods. Then, by reducing the value of K_c (Controller Gain) and I (Reset), the stable condition is achieved [2]. This is because large value of gain may lead to the instability and large value reset value may cause the present value to overshoot from the set point value [2]. The response was stable by using the value as shown in Table 6 and each of the tuning rule is tested for its performance by handling the changes in set point and load disturbance [1].

Table 6: Table of Tuning Rules for Open Loop Method

Tuning Rule	Gain, K_c	Integral (I)
Ziegler-Nichols	2.49	13.03
Cohen-Coon	2.81	9.53
Chien, Hrones & Reswick (CHR) (0% Overshoot)	0.97	4.69
Chien, Hrones & Reswick (CHR) (20% Overshoot)	1.66	3.912
Takahashi	2.51	12.91

B. Closed Loop Analysis

1. Tuning Rules by Ziegler-Nichols

After the stable response was achieved, the curve was analysed for load disturbance and set point. From the observation, it takes 63.90 s for process to return at the set point for the load disturbance. The types of process response occur is quarter amplitude damping (QAD) and the percentage overshoot is 17 %. Besides that, for set point test, the set point is added 10% from operating process which is from 10 psig to 12.5 psig. From this observation, Ziegler-Nichols can stabilize the process by 78.24 s as shown in Figure 3. The types of process response occur for the set point test is quarter amplitude damping (QAD) while the percentage overshoot is 1.6 %. In addition, the steady state error for both load disturbance and set point is 0 error.

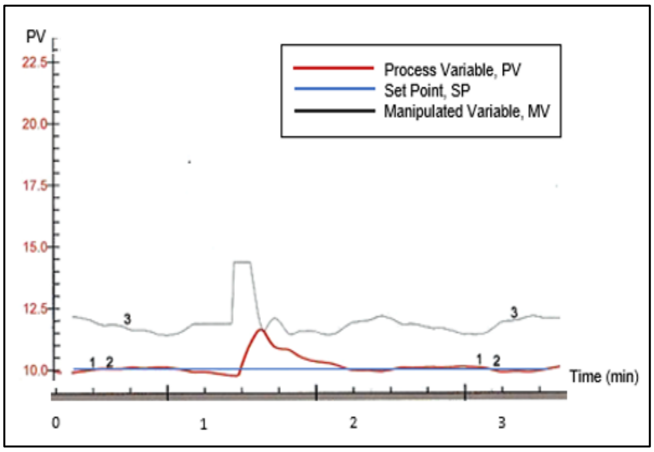


Fig 2. Closed Loop Process Response upon a Change in Load Disturbance of Ziegler Nichols (Z-N) Tuning Rule

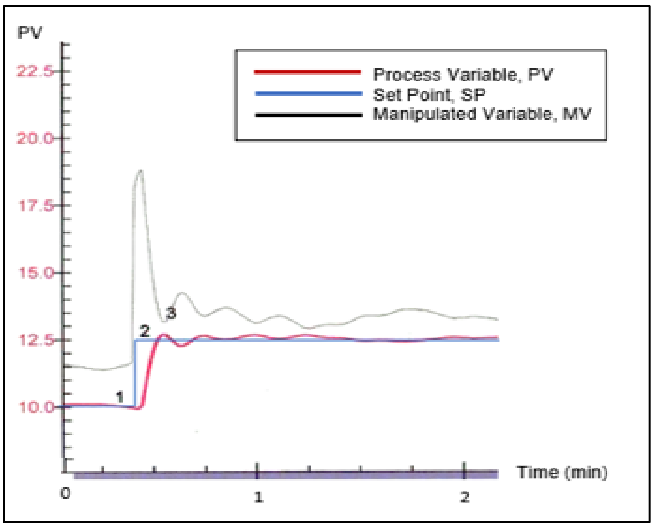


Fig 3. Closed Loop Process Response upon a Change in Set Point of Ziegler Nichols (Z-N) Tuning Rule

2. Tuning Rules by Cohen-Coon

For load disturbance, the process starts to stable and return to the set point in 59.98 s as shown in Figure 4. The types of process response occur is underdamped and the percentage overshoot is 13 %. Moreover, for set point test, the set point is added 10% from operating process which is from 10 psig to 12.5 psig. Cohen-Coon can stabilize the process which takes 76.94 s to stable as shown in Figure 5. The types of process response occur is underdamped and the percentage overshoot is 4 %. Hence, the set point error for Cohen-Coon is 0 error.

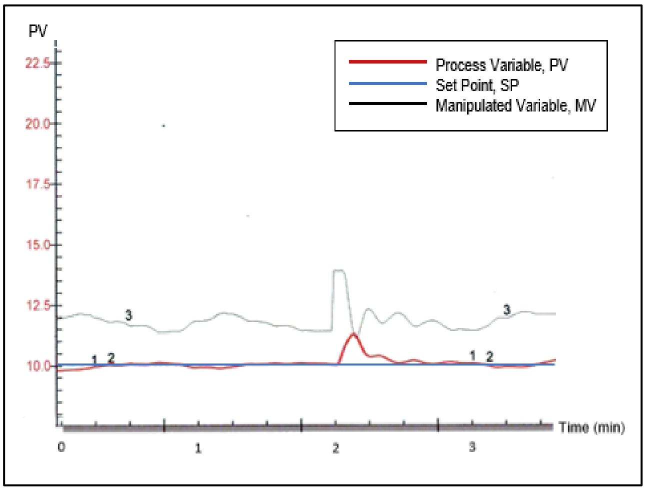


Fig 4. Closed Loop Process Response upon a Change in Load Disturbance of Cohen-Coon (CC) Tuning Rule

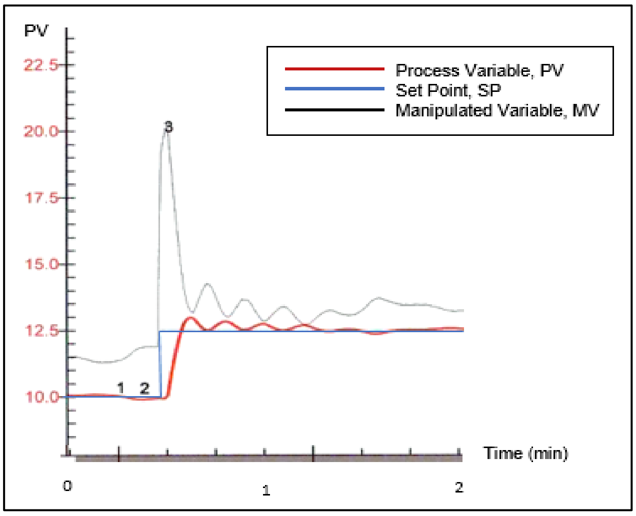


Fig 5. Closed Loop Process Response upon a Change in Set Point of Cohen-Coon (CC) Tuning Rule

3. Tuning Rules by Chien, Hrones & Reswick (CHR) (0% overshoot)

In CHR (0% overshoot) tuning rule, for load disturbance test, the process starts to stable and return at the set point in 52.26 s as shown in Figure 6. The types of process response occur is underdamped and the percentage overshoot is 8 %. For set point test, the set point is added 10% from operating process which is from 10 psig to 12.5 psig as shown in Figure 7. From the observation, CHR can stabilize the process which it takes 74.33 s to stable. The types of process response occur is underdamped and no overshoot occurred. However, the response is less stable compared to Ziegler-Nichols and Cohen-Coon for both performance test which has 0.5 error.

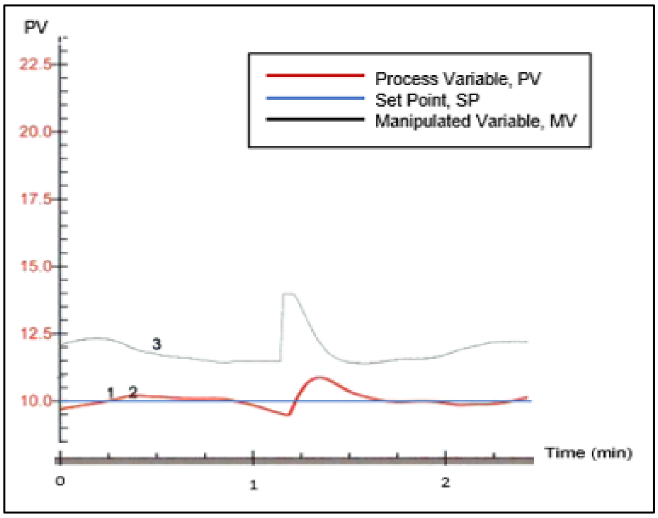


Fig 6. Closed Loop Process Response upon a Change in Load Disturbance of Chien, Hrones & Reswick (CHR) (0% Overshoot) Tuning Rule

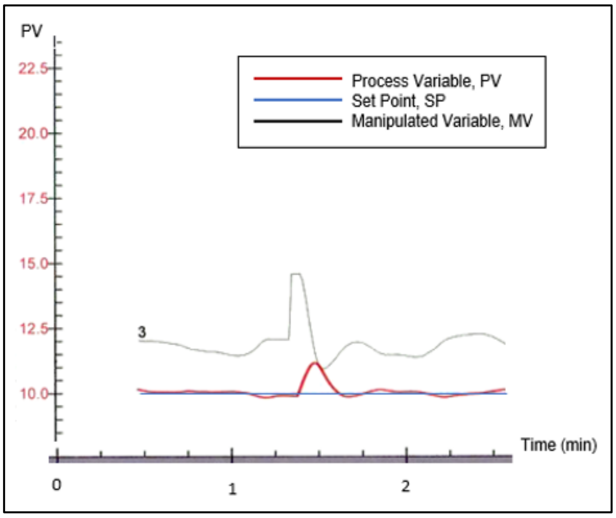
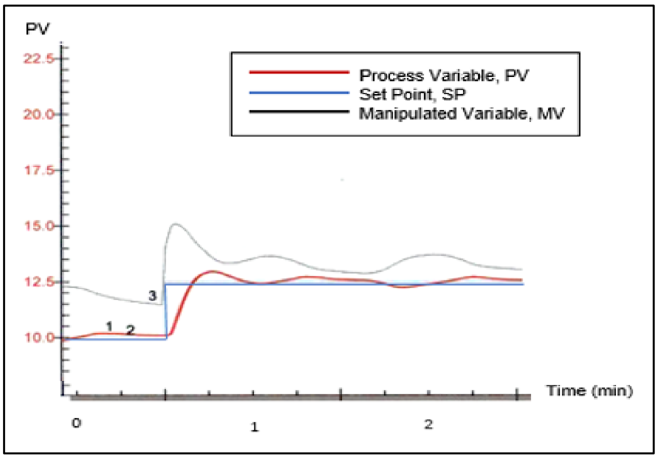


Fig 8. Closed Loop Process Response upon a Change in Load Disturbance of Chien, Hrones & Reswick (CHR) (20% Overshoot) Tuning Rule



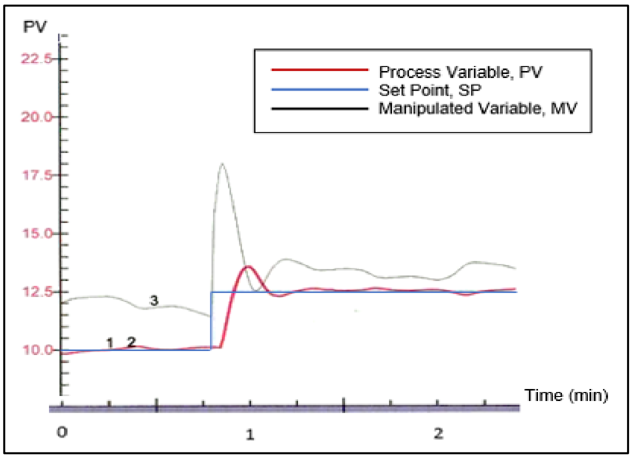


Fig 7. Closed Loop Process Response upon a Change in Set Point of Chien, Hrones & Reswick (CHR) (0% Overshoot) Tuning Rule

Fig 9. Closed Loop Process Response upon a Change in Set Point of Chien, Hrones & Reswick (CHR) (20% Overshoot) Tuning Rule

4. Tuning Rules by Chien, Hrones & Reswick (CHR) (20% overshoot)

In load disturbance test for CHR (20% overshoot) tuning rule, the process starts to stable and return at the set point in 48.25s as shown in Figure 8. The types of process response occur is quarter amplitude damping (QAD) and the percentage overshoot is 12 %. On the other hand, in set point test, the set point is added 10% from operating process which is from 10 psig to 12.5 psig. From the observation, CHR can stabilize the process which it takes 44.34 s to stable as shown in Figure 9. The types of process response occur is quarter amplitude damping (QAD) and the percentage overshoot is 8 %. Though, the response is less stable compared to Ziegler-Nichols and Cohen-Coon for both performance test which has 0.1 et point error.

5. Tuning Rules by Takahashi

In Takahashi tuning rule, for load disturbance test, the process starts to stable and return to its set point in 75.63s as shown in Figure 10. The types of process response occur is underdamped and the percentage overshoot is 15 %. For set point test, the set point is added 10% from operating process which is from 10 psig to 12.5 psig. From the observation, Takahashi can stabilize the process which takes 56.07s to stable as shown in Figure 11. This proves that the value of K_c and I is suitable at this set point. The types of process response occur is quarter amplitude damping (QAD) and 4% overshoot occurred. Furthermore, the set point error for both performance test is 0 set point error.

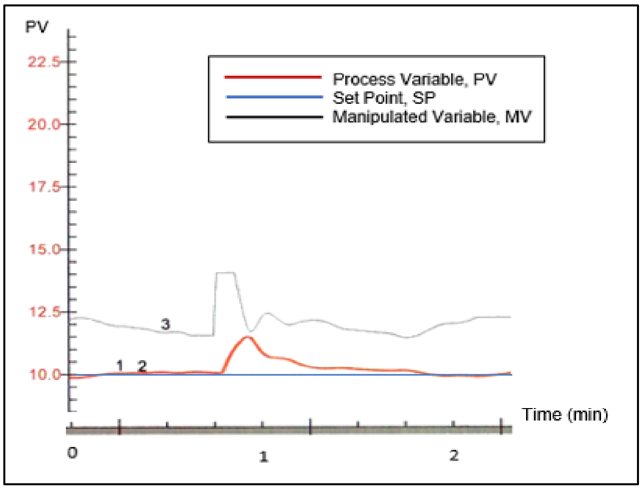


Fig 10. Closed Loop Process Response upon a Change in Load Disturbance of Takahashi Tuning Rule

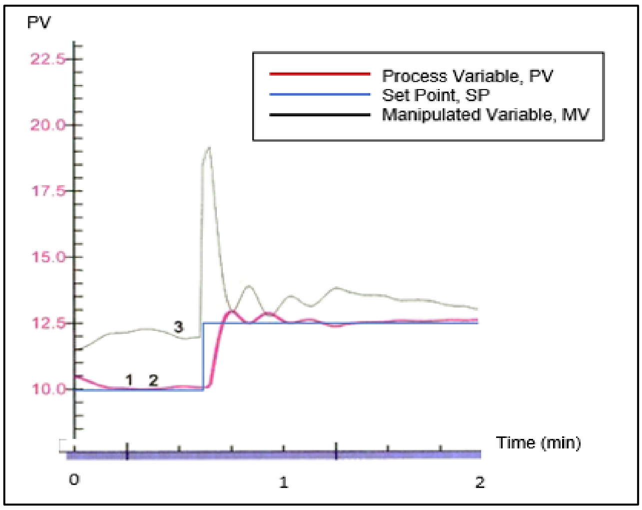


Fig 11. Closed Loop Process Response upon a Change in Set Point of Takahashi Tuning Rule

Table 7 and 8 shows the settling time, percentage overshoot, and steady state error of performance test for five differents tuning rules.

Table 7 Performance of Process Response for Load Disturbance Test

Tuning Rule	Settling Time, Ts	Percentage Overshoot, %OV	Steady state error, e
Ziegler-Nichols	63.90 s	17 %	0
Cohen-Coon	59.98 s	13 %	0
Chien, Hrones & Reswick (CHR) (0% Overshoot)	52.16 s	8 %	0.5
Chien, Hrones & Reswick (CHR) (20% Overshoot)	48.25 s	12 %	0.1
Takahashi	75.63 s	15 %	0

Table 8 Performance of Process Response for Set Point Test

Tuning Rule	Settling Time, Ts	Percentage Overshoot, %OV	Steady state error, e
Ziegler-Nichols	78.24 s	1.6 %	0
Cohen-Coon	71.72 s	4 %	0
Chien, Hrones & Reswick (CHR) (0% Overshoot)	74.33 s	0%	0.5
Chien, Hrones & Reswick (CHR) (20% Overshoot)	44.34 s	8 %	0.1
Takahashi	73.02 s	4%	0

IV. Conclusion

In conclusion, the optimum pressure controllability was studied by using different tuning rules of PID tuning. On the other hand, the total five different tuning rules was analyzed for their performances thus the most efficient tuning rule for pressure control was predicted. In this study, the system that have minimum settling time and peak overshoot and less error was considered as the best tuning rule. Thus, in this study, the Cohen-Coon method is work well on a pressure controllability because it has minimum settling time and peak overshoot and less steady state error compared to the other tuning rule.

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