Tuning of Distillation Column Control

By

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Lemma Dendena Tufa)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD FATHI ABU HANIPAH

ABSTRACT

Distillation column is one of the most important equipment in a chemical industry. It is quite a challenge to control both the composition of the bottom and top product without affecting the composition of one another. By designing a good controller and a good tuning for a controller, a distillation column can be controlled efficiently and a product with a high quality can be obtained. A few methods are applied in this project which is by first designing a controller which is a PID controller and a MPC controller. Once the designing of the controller is done, an algorithm is developed to make sure that the tuning of distillation column control can be done efficiently. Then, the controller tuning setting is tested using matlab and the result of each approach is compared and the best result is selected to control the distillation column. Lastly, a performance evaluation is done in order to make sure that the controller tuning does not damage the valve. Therefore, by studying on tuning of distillation column control the composition of the bottom and the top product can be control and the product of a distillation column can be obtain according to the desired value.

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CHAPTER 1: INTRODUCTION

1.1 Background Study

Distillation is defined as a process in which a liquid or vapour mixture or more substances is separated into its component fractions of desired purity by the application and removal of heat. Distillation is a common separation technique and it contributes to more than 50% of plant operating costs [1]. Basically distillation is where heat is used to separate the more volatile liquid from the less volatile liquid. Therefore the main purpose of distillation is to make sure that the original mixture will contain more of the less volatile compound. After the separation is done the vapor will be cooled and condensed and therefore, the condensed vapor will contain more of the volatile compound. Basically the distillation process requires three criteria. The first criterion is where both phase of the components must be present and can have a contact on each other in the separation column. Secondly the component must have different volatilities so that two phases can coexist for the separation. The third criterion is that the two phases can be separated [2].

A distillation column is where mixtures of liquid can be separated by a process of recondensation and evaporation [3]. The basic principle of this is that liquid will evaporate at a different temperature. Therefore heat is a major contribution to this process. A distillation column is one of the most important equipment in chemical plants all around the world.

Process control is a basic engineering feature that deals with algorithms and mechanism of a specific process for a desired range to get a desired product. Process control is very important in order for the process to run efficiently and to get the desired product. Without process control it would be impossible to operate modern plant safely and profitably to get the desired product and to comply with the environmental requirement. [4]

Process control in a distillation column is very important to regulate the temperature, the pressure, flow rate and many other factors which can affect the quality of the distillate and the bottom product. There are many methods which can provide an efficient process control for the distillation column.

1.2 Problem Statement

Control system in distillation column is a complex process. This is because of the composition which is dependent on each other; the composition of the top will change according to the composition in the bottom and vice versa. By controlling the composition of the bottom, the composition of the top has to be controlled too in order to make sure both of the products of the distillation column met the desired value. Therefore, the methods used to control and tuning to maintain both compositions are very important and require a very detail study on the strategy of control.

1.3 Objectives

The objectives for the project title of "Tuning of a Distillation Column Control" are as following:

a. Tuning the PID and MPC controller so that the upset of the controller can be reduced and to make sure that the controller is optimized.
b. To compare types of different tuning control strategy and select which of the tuning control strategy best fit the process of separation in the distillation column using the wood and berry distillation column model.

1.4 Scope of Study

The scopes of study for the project title of "Tuning of a Distillation Column Control" are as following:

a. Analysis on the type of controllers tuning on the wood and berry distillation column model.
b. Simulation on the controller tuning chosen to be used as a control strategy tuning on the wood and berry distillation column model.

CHAPTER 2: LITERATURE REVIEW

Distillation column is one of the most important equipment in chemical plants all around the world. Hence, it is understood that the process control of a distillation column is probably one of the most studied area in the industry. It is very important to implement a good tuning control method in a distillation column as a distillation column can affect the overall process plant. There are a various types of process control tuning which can be implemented in a typical control of a distillation column.

2.1 PID Controller Tuning

PID controller stands for Proportional Integral and derivative controller uses a control loop feedback mechanism. There are a few methods of tuning a PID controller; auto-tuning based on process step response and damping, firefly algorithm and using the Internal Model Control (IMC) Based PID Controller Tuning Strategy.

2.1.1 Auto-Tune Based On Step Response and Damping

The PID controller tuning is based on the n-th order lag (PTn) process model and by applying the damping optimum criterion. The PTn model identification is on the process step response of the system [5]. To work with the higher order dynamics, while in the same time having a simple dead-time-free process model formulation, the PTn model can be used. The PTN model and FOPDT model parameters are given through the equivalence of process model step response flexion tangent [6, 7]. The PID controller tuning is based on the damping optimum criteria. The application in the control system that was found in the damping optimum criterion needs to be tuned in a precise manner

[8-10]. The transfer function of the closed-loop system in fig. 1 was derived assuming the PID controller is ideal [5].

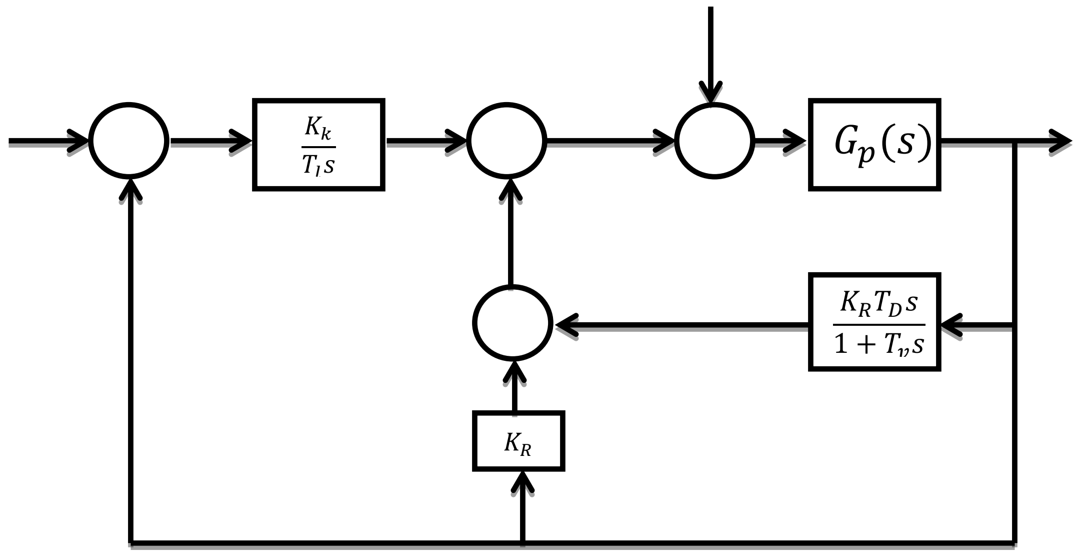


Figure 1 : Block diagram of control system with modified PID controller [5]

$$G_c(s) = \frac{1}{A_c(s)} = \frac{1}{1+T_e s+D_2 {T_e}^2 s^2+D_3 {D_2}^2 {T_e}^3 s^3 \ldots\ldots + D_l {D^2}_{l-1} \ldots\ldots {D_2}^{l-1} {T^l}_e s^l} \qquad (1)$$

Where: Te = time constant of the overall closed-loop system

D2,D3…..,Di = damping optimum characteristic ratios

l = closed-loop system order (l = n + 1 in the case of PID controller)

$$G_c(s) = \frac{y(s)}{y_R(s)} = 1 \Bigg/ \left(\begin{array}{l} 1 + \frac{(1+K_R K_p) T_l s}{K_R K_p} + \frac{(K_R K_p T_D + a_1) T_l s^2}{K_R K_p} \\ + \frac{a_2 T_l s^3}{K_R K_p} + \frac{a_3 T_l s^4}{K_R K_p} + \cdots + \frac{a_n T_l s^{n+1}}{K_R K_p} \end{array} \right) \tag{2}$$

The characteristic ratio are set to the values D2 = D3 =…= Di = 0.5 are so-called "optimal". This closed-loop tuning may be regarded optimal in cases where the overshoot is small and the related well-damped behavior is critical [5]. By using a very large Te value, the control system robustness is improved and the sensitivity of the noise is decreased but it causes a slow response and a less efficient disturbance rejection [5]. The response damping is adjusted by varying the ratios of D2, D3…, Di, where the damping of dominant closed-loop dynamics is influenced by the ratio D2 [5].

The PID controller can be adjust only the closed loop characteristic ratio D2, D3 and D4, therefore the expression of PID controller gain K_R , integral time constant T_l and the derivative time constant T_D are obtained by using the lower-order coefficient of the characteristic polynomial (2) with the lower coefficient (1) up to s^4, which can be given with the analytical expression [5]:

$$K_R = \frac{1}{K_p}\left(\frac{n(n-1){T_p}^2}{2{D_2}^2 D_3 {T_e}^2} - 1\right) \tag{3}$$

$$T_l = \left(1 - \frac{2{D_2}^2 D_3 {T_e}^2}{n(n-1){T_p}^2}\right) T_e \tag{4}$$

$$T_D = D_2 T_e T_p n \frac{(n-1)T_p - 2D_2 D_3 T_e}{n(n-1){T_p}^2 - 2{D_2}^2 D_3 {T_e}^2} \tag{5}$$

With the closed loop equivalent time constant Te, given as follows (valid for n>2) [5].

$$T_e = \frac{(n-2)T_p}{3D_2D_3D_4} \tag{6}$$

The expression above shows that the PID controller parameters K_R, T_I, T_D, are influenced by the dominant characteristic ratio of D2 and D3. While the ratio of D4 only affects the equivalent time constant, Te. Therefore, the closed-loop response speed and dominant-mode damping tuning can be decoupled effectively, as the damping of the dominant closed-loop system modes is determined by the choice of the most dominant characteristic ratio D2, and the response speed primarily depends on the closed-loop equivalent time constant Te [5]. By setting the response to (D2=D3=D4=0.5) and the PTn process models characterized by using the Kp=1,Tp=10s and model orders in the range of 3-6 the response of the tuning of the closed-loop system result in a well-damped control system response with respect to both the product and the disturbance [5].

2.1.2 Firefly Algorithm Approach

A PID controller involves three separate elements; the proportional, integral and derivative values. The P value determines the reaction to the current error, the I value determines the reaction based on the sum of recent errors and the D value determines the reaction based on the rate at which the error has been changing [6]. Performance of the traditional firefly algorithm depends on its control parameters and often suffers from being trapped in a local optimum [6]. The Tinkerbell map approach can enhance the diversity of the fireflies and actuate the firefly to move out of the local near-optimal solution [6]. The firefly algorithm is given by the equation (7) [7, 8].

$$v_i = v_i + \beta_o e^{-\gamma r_{ij}^{2}}\left(v_j - v_i\right) + \alpha(rand - \tfrac{1}{2}) \tag{7}$$

Where: *y* – absorption coefficient

Bo- attractiveness at r =0

The third term is randomization with *a* – randomized parameter

Rand – random number generated uniformly distributed in [0, 1]

Given the iteration for modified firefly algorithm (MFA) by iterating the values of *a* and *y* by the equations (8) and (9) [6].

$$\alpha = \left(a_f - a_i\right) \cdot {}^{Generation}/_{MaxGenerations} + \alpha_i \quad (8)$$

$$\gamma = \left(\gamma_f - \gamma_i\right) \cdot {}^{Generation}/_{MaxGeneration} + \gamma_i \quad (9)$$

Where: a_i– initial value of linear function to tune *a*

af – final value of linear function to tune *a*

y_i – initial value of linear function to tune *y*

y_f – initial value of linear function to tune *y*

A chaotic firefly algorithm (CFA) approach is proposed based on Tinkerbell map. The two-dimensional quadratic map is given by the equation. [6]:

$$x_{t+1} = {x_t}^2 - {y_t}^2 + a \cdot x_t + b \cdot y_t \quad (10)$$

$$y_{t+1} = 2x_t y_t + c \cdot x_t + d \cdot y_t \quad (11)$$

Where: a,b,c,d – non zero parameters

t – Iteration

In the proposed CFA the FA eq. (7) is modified by eq. (12) using the new variables, Φ and ƛ. It is modified by:

$$v_i = v_i + \beta_o e^{-}\gamma r^2{}_{ij}(v_j - v_i) + \emptyset(rand - \tfrac{1}{2}) \tag{12}$$

$$\gamma = |G| \cdot x^*{}_{t+1} \cdot {}^{Generation}/_{MaxGenerations} \tag{13}$$

$$\emptyset = (\emptyset_f - \emptyset_i) \cdot {}^{Generation}/_{MaxGenerations} \tag{14}$$

Where: G – signal generated using normal distribution with zero mean and variance

|G| - absolute value of G

Φ – Decreasing linear function with initial and final values.

In terms of CFA of x_{t+1} are the normalized value of x_{t+1} generated by the tinkerbell map with a range values of [0,1]. The values of T are generated by using the equation (13) and (14). The linear scaling function in range [0, 1] transforms a variable x_{t+1} to $x^*{}_{t+1}$ in the following equation:

$$x^*{}_{t+1} = \frac{x_{t+1} - \min(x)}{\max(x) - \min(x)} \tag{15}$$

Where: *X* - (*X1,…, XT)*

T – Number of iterations

Min(x) – minimum values of x_{t+1}

Max(x) – maximum values of x_{t+1}

Based from the result obtained by applying FA, MFA, CFA, GA and PSO to tune the PID controller when applying wood and berry column model, it is proven that CFA is the best performer followed by MFA and FA in terms of minimum and mean objective function in 30 runs [6]. From the result that shows the best gains obtained for the PID controller, it is observed that CFA is the best performer compared to other controller [6].

2.1.3 Internal Model Control (IMC) Based PID Controller Tuning Strategy

The idea of IMC came from the time delay compensator as proposed by Smith [9]. Generally the concept of IMC was involved in a designing a control system was purposed by Garcia et al. [10]. IMC's main characteristic is that it has a simple structure and it requires fewer parameters to be tuned on-line and is easily tuned [9]. It also has a significant effectiveness in enhancing the robustness and control performance of system with a long time delay [9]. By combining the IMC and PID controller, the tuning and optimization of the controller parameters has become more convenient and it is easier to achieve in DCS systems [9]. Controller system design is expected to provide a fast and a very accurate set-point tracking, which is the output of the system, should follow the input of the system as accurate as possible and the disturbance must be corrected by the control system efficiently [11]. IMC is a control strategy based on the mathematic model to design a controller [9]. Figure 2 shows the structure of an IMC control system [9].

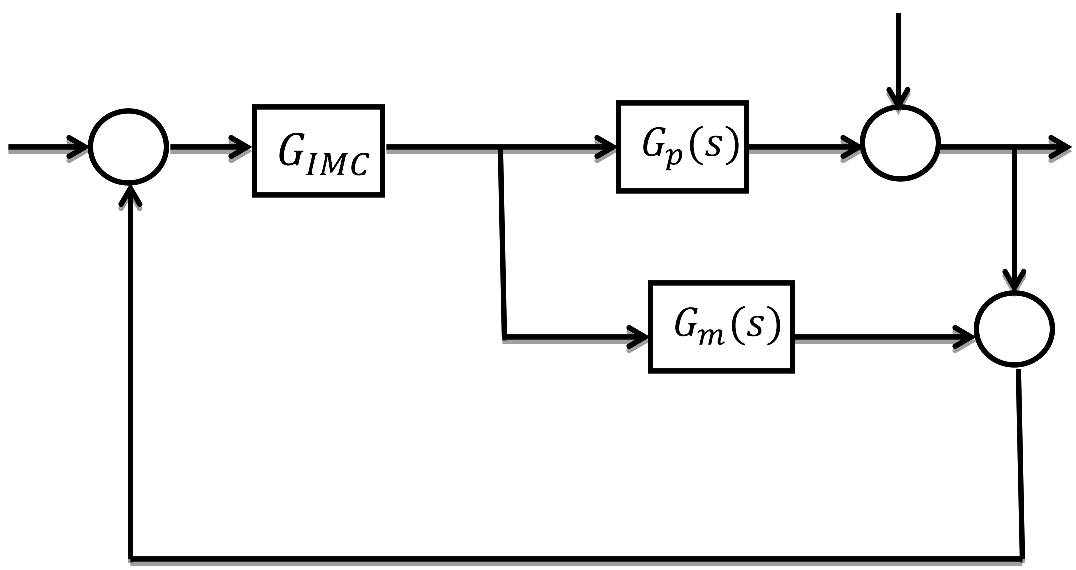


Figure 2: Block Diagram of IMC structure [9]

By using the IMC-PID in practical industry processes, the controller can be optimized and tuned to be better [9].

2.2 Model Predictive Control (MPC)

A predictive controller is used widely in the industry nowadays. An MPC controller basically uses models in two ways; using a model to estimate the effect of past control moves on P (prediction horizon) future output, in a case of no future moves, and using the same model to produce the optimal M (control) moves. [10]. Most of the chemical process nowadays dynamic matrix control is the most popular for the MPC algorithm [10]. Tuning the controller is a direct way to reach the optimum performance for a controller. Tuning a controller using the Ziegler-Nichols, Lopez, Ciancone, etc. [11] are some of the example of using a single-loop tuning in P, PI and PID controllers. [10]. An MPC controller uses a tuning strategy for unconstraint SISO and multivariable MPC. [12]. MPC controller offers a better performance compared to PI/PID controller, specifically in multivariable processes. Using the MPC controller using tuning strategy in the OLMR (Ogunnaike, Lemaire, Morari and Ray) (3X3) distillation column model produces an excellent performance. [10]

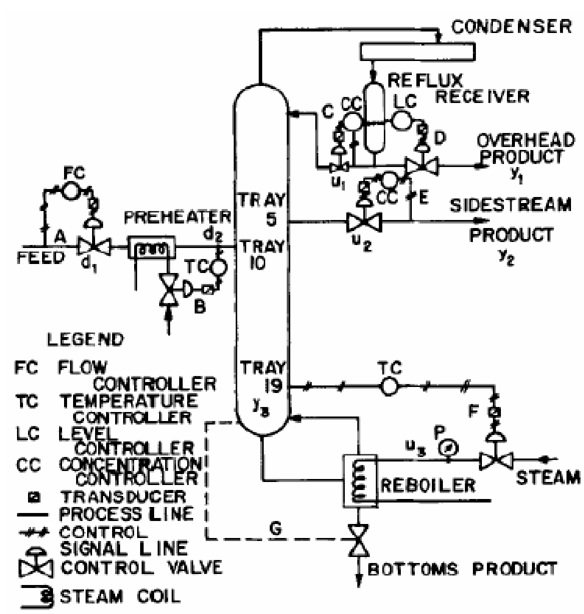


Figure 3: Schematic diagram of OLMR distillation column [13]

2.2.1 On-line tuning strategy

MPC has a set of tuning parameters; it can be used to fine-tune the closed-loop response for good performance and stability. The parameters are adjusted using the trial and error procedure [14]. A typical MPC feedback system is shown in Figure 7 [14].

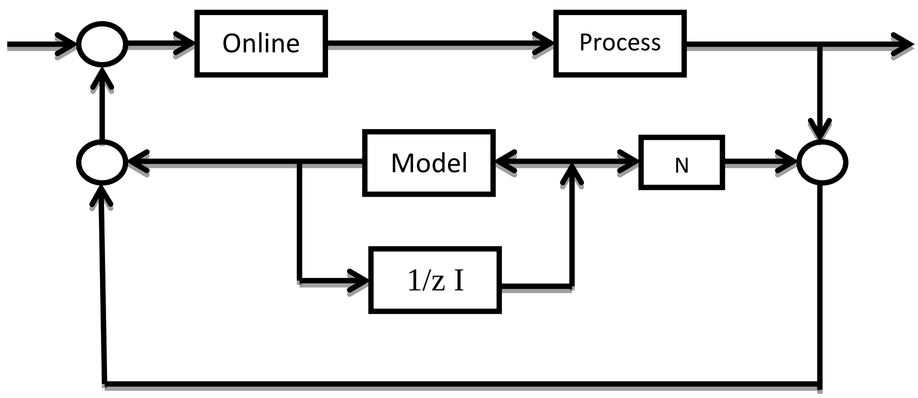


Figure 4: Typical MPC feedback system [14]

The adaptation strategy of the MPC parameters is applicable to both unconstrained and constrained MPC, can be achieved by exploitation of the sensitivity of the closed loop response to the tuning parameters [14]. The analytical expression for the sensitivity of the closed loop response of MPC with respect to the output weight and input weights tuning parameters [14]. The on-line adaptation strategy focuses on a linear approximation of the relationship between the output and the MPC tuning parameters [14]

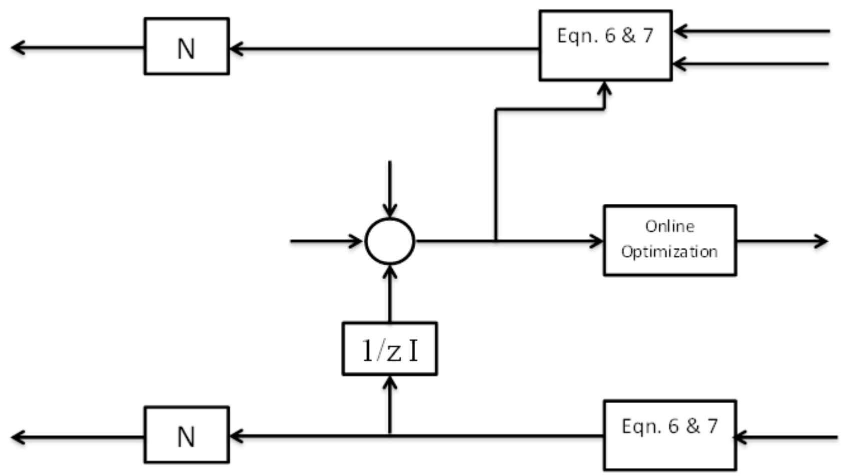


Figure 5: MPC closed-loop response prediction [14]

The result of the tuning strategy on a three-product distillation column is shown in figure 9. Noticeable improvement on the result of the product behavior using this due to the adaptation is observed when MPC is unconstraint. When MPC is unconstrained, the closed-loop response of all variable shows a very good response [14].

2.2.2 Analytical Approach

MPC tuning parameter includes the prediction and control horizons and the weight matrices using the cost function. MPC tuning problem is an active constraint considerably complicates and causes problem [15]. Based on the result of tuning using the analytical approach, the result of the simulation is shown in figure 11 using the wood-berry distillation column process [15]

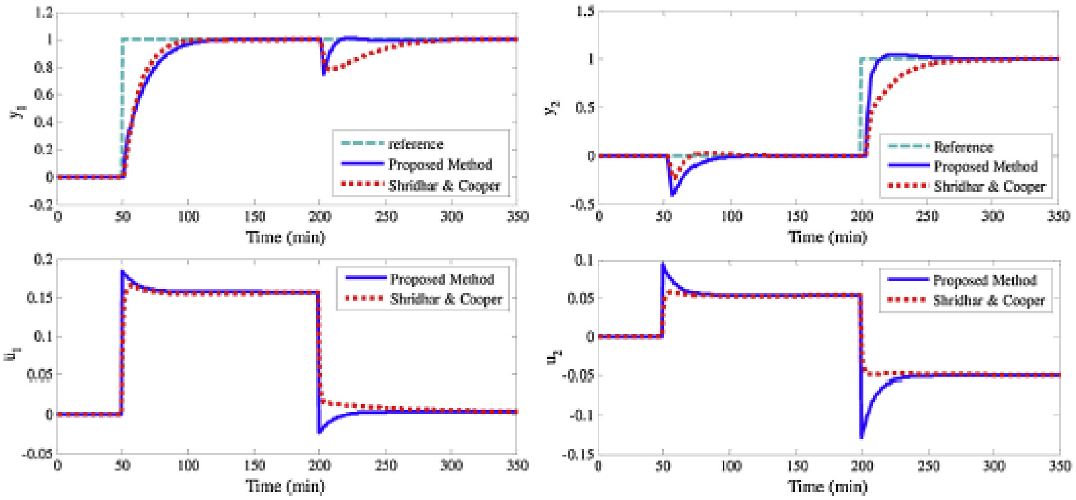


Figure 6: Closed loop responses of wood and berry plant [15]

The result shows the effectiveness of using the analytical approach tuning strategy using MPC controller [15].

CHAPTER 3: METHODOLOGY

The methodology for the project will be on the simulation test on the response of the tuning strategies that are going to be used.

3.1 Design of Control Process

First the selection of the type of control strategy that are going to be used, there are basically three types of tuning control strategy that can be used for the PID controller and two types of tuning control strategy which can be used for the MPC controller; the design of the process control will be based on the wood-berry distillation column approach eqn. (19).

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = \begin{bmatrix} \frac{12.8e^{-s}}{16.7s+1} & \frac{-18.9e^{-3s}}{21.0s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & \frac{-19.4e^{-3s}}{14.4s+1} \end{bmatrix} \begin{bmatrix} u_1(s) \\ u_2(s) \end{bmatrix} + \begin{bmatrix} \frac{3.8e^{-8.1s}}{14.9s+1} \\ \frac{4.9e^{-3.4s}}{13.2s+1} \end{bmatrix} F(s) \tag{19}$$

Where: y_1 – Composition of Top Product (mol fraction)

y_2 – Composition of Bottom Product (mol fraction)

u_1 – Reflux flowrate

u_2 – Steam Flowrate

y_1 – Feed Flowrate

3.1.1 Feedback Control

A feedback control works by measuring the controlled variables and manipulate the manipulated variable. A feedback controller is developed by determining all three variables which are; manipulated variable, controlled variable and disturbance variable. After determining the variables a block diagram is purposed and the transfer functions are develop. After developing the transfer function the controller is tuned. There are a few methods which can be used to tune a PID controller which are auto-tuned based on step change, the chaotic firefly algorithm and IMC based PID controller tuning strategy

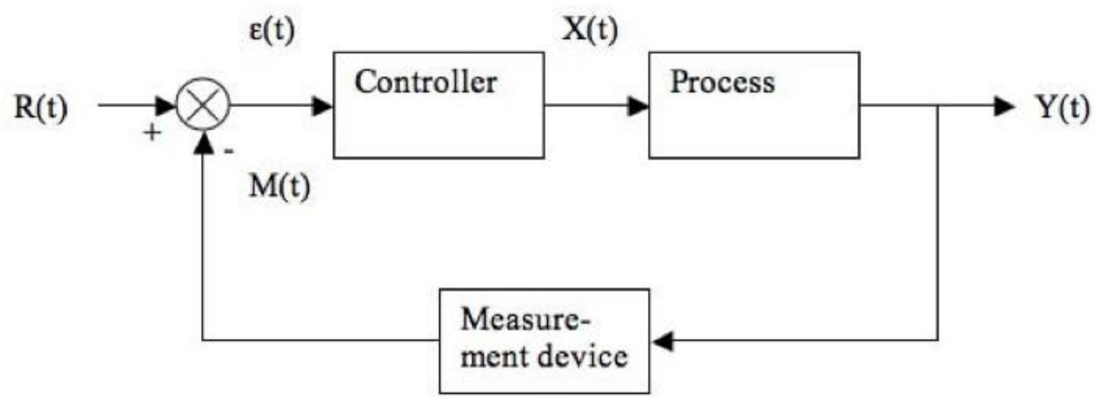


Figure 7: Basic Feedback controller

3.1.2 Model Predictive Controller

A model predictive controller used a prediction method which predicts the future control input and future responses. The prediction is done using a model and optimized at regular intervals with respect to a performance index. A formula to determine the type of receding horizon control for the distillation column control was determined. Lastly the tuning of the MPC is done in order to optimize the performance. By analyzing the effect of increasing and decreasing of each parameter for the controller the result for each and every parameter is tested and the performance is recorded.

3.2 Tuning Of Controller

Tuning the controller will be used based on different types of controller tuning approach. By using a certain type of algorithm to produce tuning method for MPC and PID controller and applying it to the matlab software the method of tuning can be simulated and the result of each tuning can be obtained.

Table 1: Methods that are going to be used

PID Controller	MPC Controller
• Internal Model Control • Ziegler Nichols • Tyreus Luyben	• Heuristic Method

IMC PI and PID controller

The IMC controller is designed in two steps:

Step 1:

The transfer function is factored as:

$$\tilde{G} = \tilde{G}_+ \tilde{G}_- \qquad (1)$$

Where:

$\tilde{G}_+ = transfer\ function\ with\ time\ delays$

$\tilde{G}_- = the\ rest\ of\ the\ transfer\ function$

Step 2:

The IMC controller is specified as:

$$G_c^* = \frac{1}{\tilde{G}_-} f \qquad (2)$$

Where:

$f = filter\ with\ a\ steady\ state\ gain\ of\ one$

$$f = \frac{1}{(\tau_c s + 1)^r} \qquad (3)$$

Where:

$\tau_c = desired\ closed - loop\ time\ constant$
$r = 1$

To get the values of the gain and integral time (PI) the Taylor series expansion must be used.

$$e^{-\theta s} \approx 1 - \theta s \quad (4)$$

To get the gain, integral time and derivative time (PID), Pade approximation must be used.

$$e^{-\theta s} \approx \frac{1 - \frac{1}{2}\theta s}{1 + \frac{1}{2}\theta s} \quad (5)$$

Tuning using Ziegler Nichols and Tyreus and Luyben

The Ziegler Nichols and Tyreus Luyben method of tuning is based on the continuous cycling method based on trial and error procedure:

Step 1:

First a steady state must be reached and determine for the controller, next we eliminate the integral and derivative control action by setting the T_D to zero and T_i to the largest possible value.

Step 2:

Set K_c equal to a small value and find the response for the controller

Step 3:

Introduce a small set point change so that the controlled variable moves away from the set point. Increase the value of K_c a little at a time until continuous cycle is observed. The continuous cycle refers to a cycle with constant amplitude. The value of K_c that produces continuous cycle is called ultimate gain, $K_{cu.}$ The period of corresponding sustained oscillation is called the ultimate period, P_u.

Step 4:

Calculate PID controller setting using Ziegler Nichols (Z-N) and tyreus-luyben settings.

Table 2: Settings for Ziegler Nichols and Tyreus Luyben

Ziegler-Nichols	K_c	T_i	T_D
PI	0.45 K_{cu}	P_u/1.2	-
PID	0.6 K_{cu}	P_u/2	P_u/8
Tyreus-Luyben	Kc	T_i	T_D
PI	0.31 K_{cu}	2.2P_u	-
PID	0.45 K_{cu}	2.2P_u	P_u/6.3

3.3 Simulation by using Simulink

The simulation is done by using simulink in matlab. The result of the simulation will be used and comparison on the type of response on the controller tuning of PID and MPC will be taken.

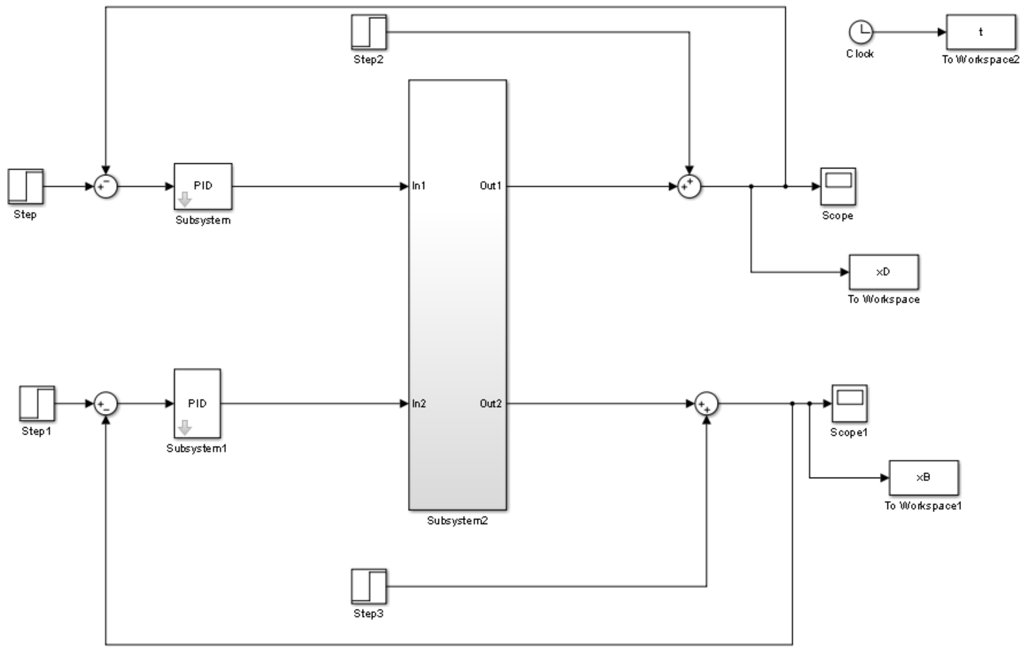


Figure 8: Wood & Berry Distillation Column using PID controller

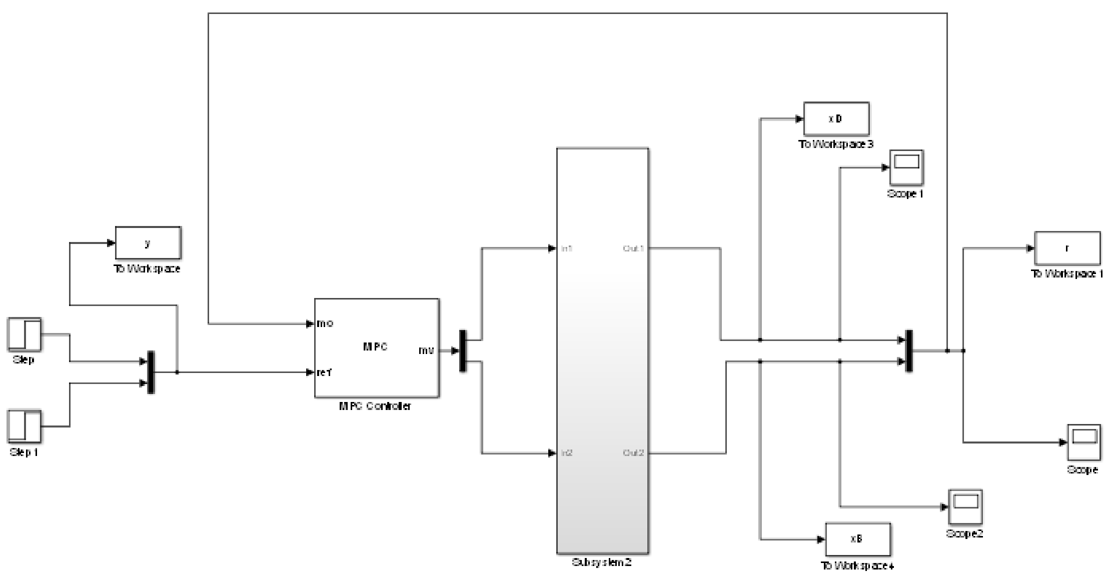


Figure 9: Wood & Berry Distillation Column using MPC controller

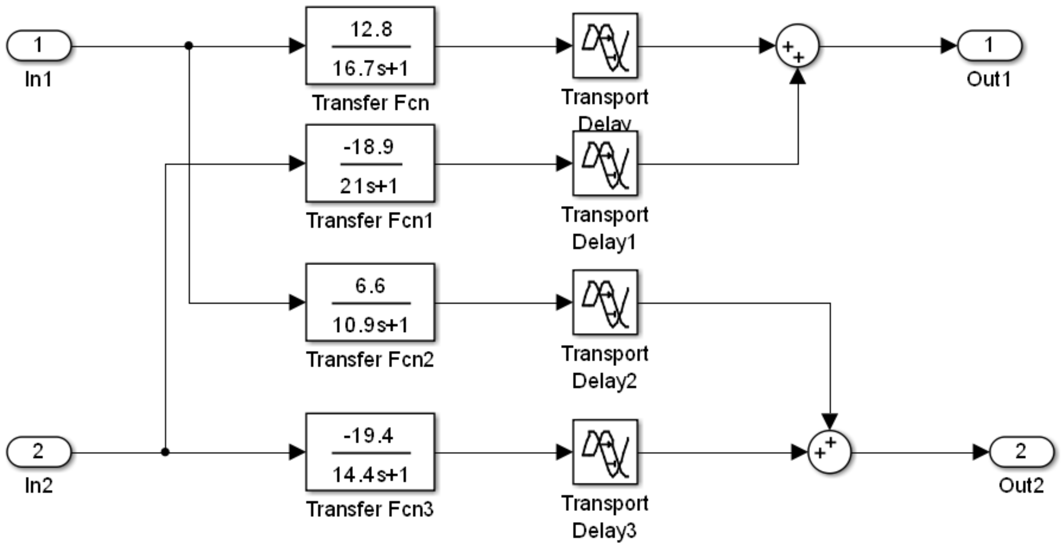


Figure 10: Wood & Berry Distillation Column

3.3.1 Quality of Control and Integral Error Are Determine

Once the tuning is done on the tuning setting selected, the errors for the tuning setting is done using three methods which are finding the IAE (integral absolute error), ISE (integral squared error) and ITAE (integral time absolute error) to know the errors and the quality and performance of the valve after tuning is done.

IAE formula:

$$IAE = \int_0^\infty |e(t)|dt \tag{6}$$

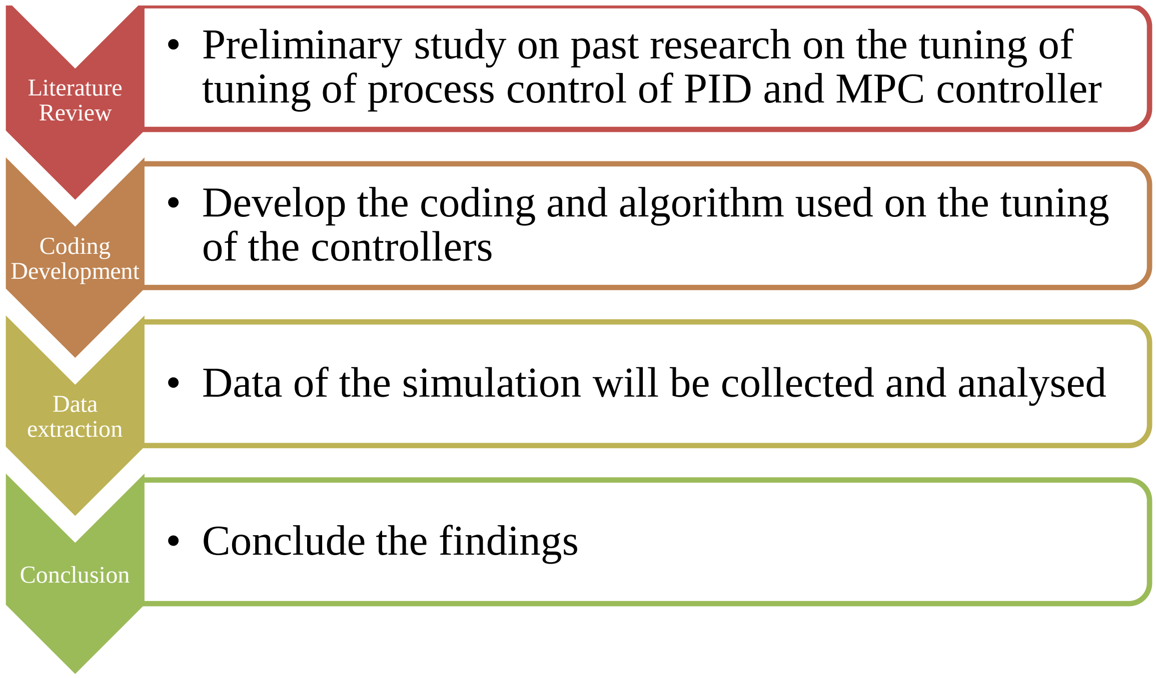
ISE formula:

$$ISE = \int_0^\infty e(t)^2 dt \tag{7}$$

ITAE formula:

$$ITAE = \int_0^\infty t|e(t)| dt \tag{8}$$

3.4 Milestone



3.5 Gantt Chart

FYP 1															
No	**Subject**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**Topic Selection**														
2	**Background Study and literature reviews**														
3	**Identifying the Problem Statement**														
4	**Extended Proposal**														
5	**Study on the types of controllers to be used**														
6	**Proposal Defence**														
7	**Introduction to matlab**														
8	**Development of transfer functions**														
9	**Development of the tuning strategy**														
10	**Selection of the controller settings and tuning strategy**														
11	**Simulation on the controller strategy**														
12	**Draft Report**														
13	**Final Report**														

FYP 2															
No	**Subject**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
14	**Lab simulation on the controller strategies**														
15	**Pilot plant testing**														

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results for PID Controller

The results obtain from the settings of the tuning for the distillation column is shown below.

<u>4.1.1 IMC controller settings on PI controller</u>

Tuning settings:

Table 3: Tuning setting for IMC PI controller

	K_c	τ_i	τ_D
X_D	0.65	0.04	0
X_B	-0.124	14.4	0

Results:

Set point tracking

Conditions:

x_{Dsp} *from* 0 *to* 1

x_{Bsp} *no changes*

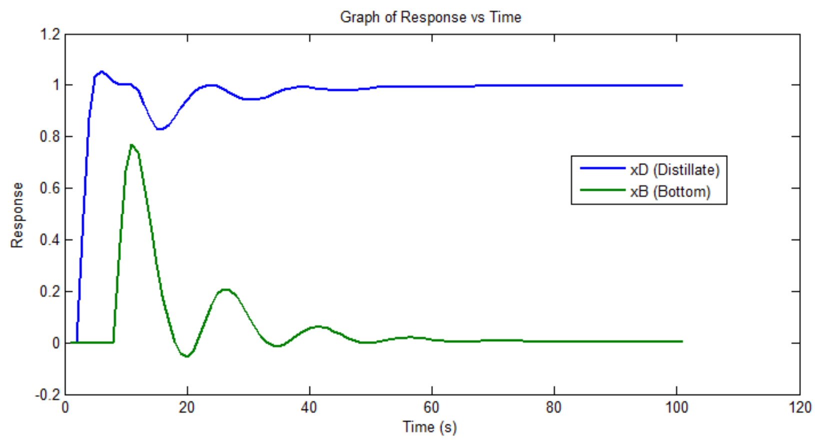


Figure 11: Response for set point tracking after tuning IMC based PI controller.

Based on the result shown from the set-point tracking, the PI controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditions:

x_{Dsp} $no\ changes$

x_{Bsp} $0\ to\ 1$

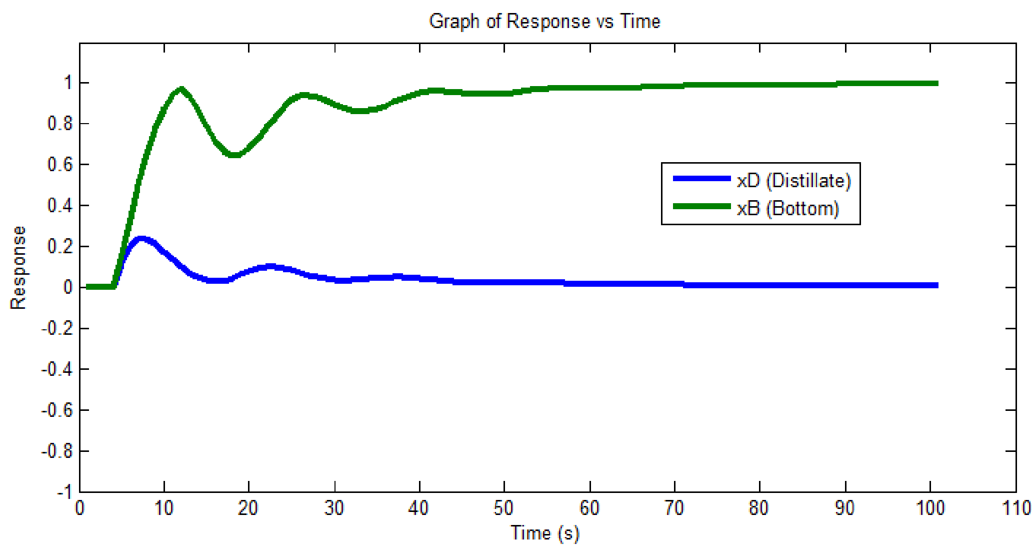


Figure 12: Response for set point tracking after tuning IMC based PI controller.

Based on the result shown from the set-point tracking, the PI controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Disturbance Rejection

Conditons:

$F_1\ from\ 0\ to\ 1$

$F_2\ no\ changes$

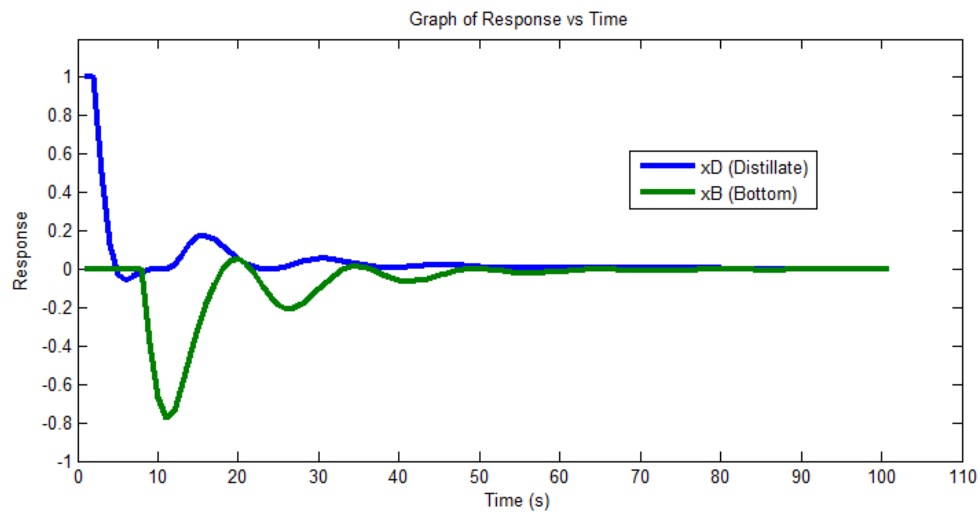


Figure 13: Response for disturbance rejection after tuning IMC based PI controller.

Based on the result shown from the disturbance rejection, the PI controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditons:

F_1 *no changes*

$F_2 from\ 0\ to\ 1$

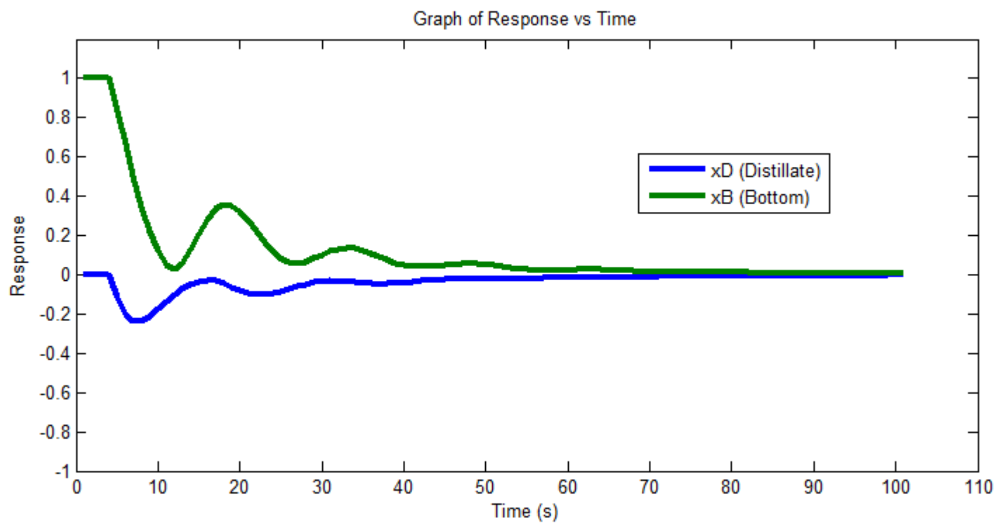


Figure 14: Response for disturbance rejection after tuning IMC based PI controller.

Based on the result shown from the disturbance rejection, the PI controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Table 4: Results for IAE, ISE and ITAE based on the response obtained from the IMC (PI) controller

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	IMC (PI)	xD	4.1630	1.9292	55.7563
					xB	6.4598	2.7011	122.537
0	1	0	0		xD	3.7223	0.3834	93.842
					xB	11.8722	6.0414	194.392
0	0	1	0		xD	4.163	1.9292	55.7563
					xB	6.4598	2.7011	122.537
0	0	0	1		xD	3.7223	0.3834	93.842
					xB	11.8722	6.0414	194.392

4.1.2 IMC controller settings on PID controller

Tuning settings:

Table 5: Tuning setting for IMC PID controller

	K_c	τ_i	τ_D
X_D	0.896	17.2	0.48
X_B	-0.182	15.89	1.36

Results:

Set point tracking

Conditions:

$x_{Dsp}\ from\ 0\ to\ 1$

$x_{Bsp}\ no\ changes$

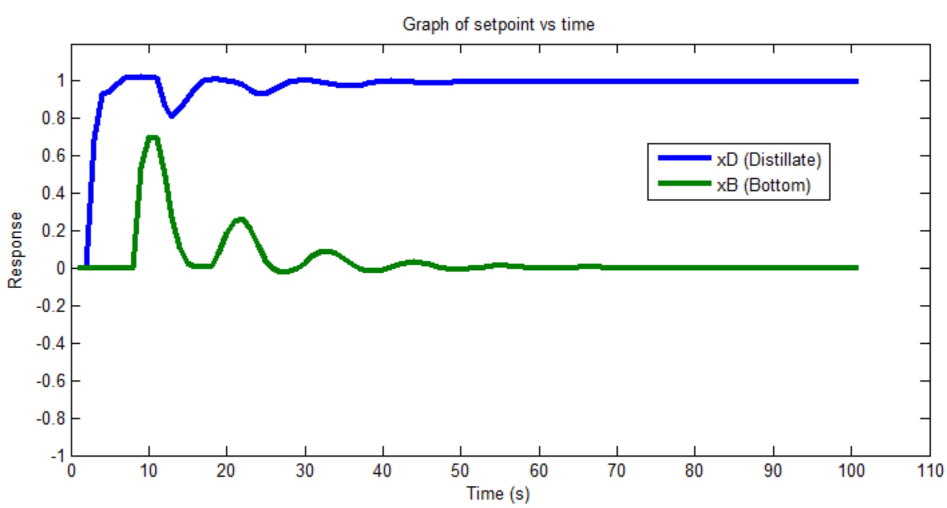


Figure 15: Response for set point tracking after tuning IMC based PID controller.

Based on the result shown from the set-point tracking, the PID controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditions:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 1

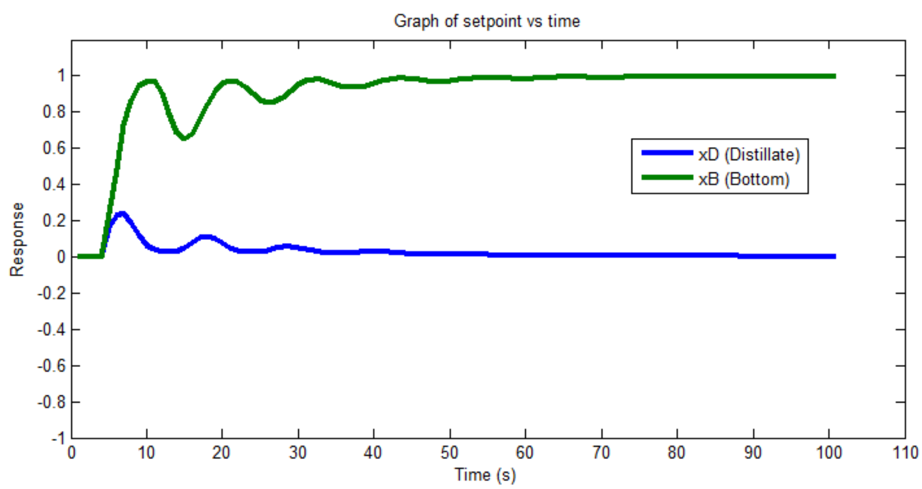


Figure 16: Response for set point tracking after tuning IMC based PID controller.

Based on the result shown from the set-point tracking, the PID controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Disturbance Rejection

Conditons:

$F_1\ from\ 0\ to\ 1$

$F_2\ no\ changes$

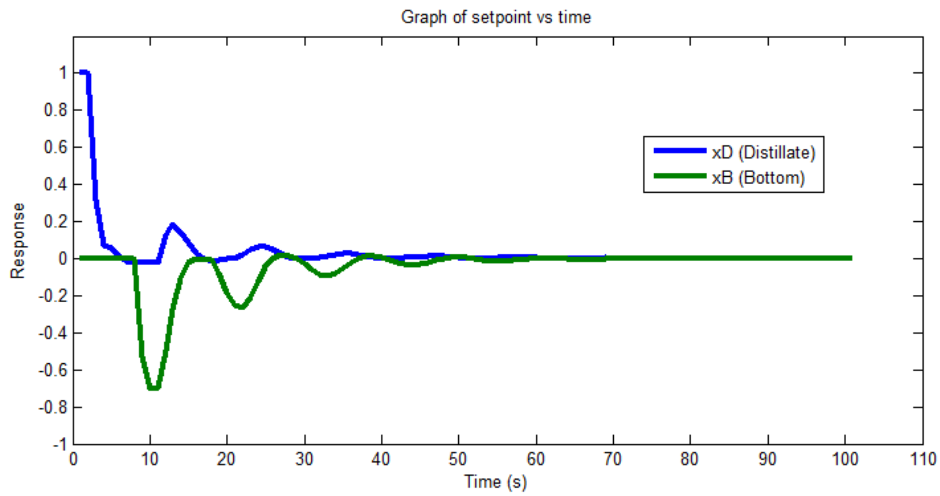


Figure 17: Response for disturbance rejection after tuning IMC based PID controller.

Based on the result shown from the disturbance rejection, the PID controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditons:

F_1 *no changes*

F_2 *from* 0 *to* 1

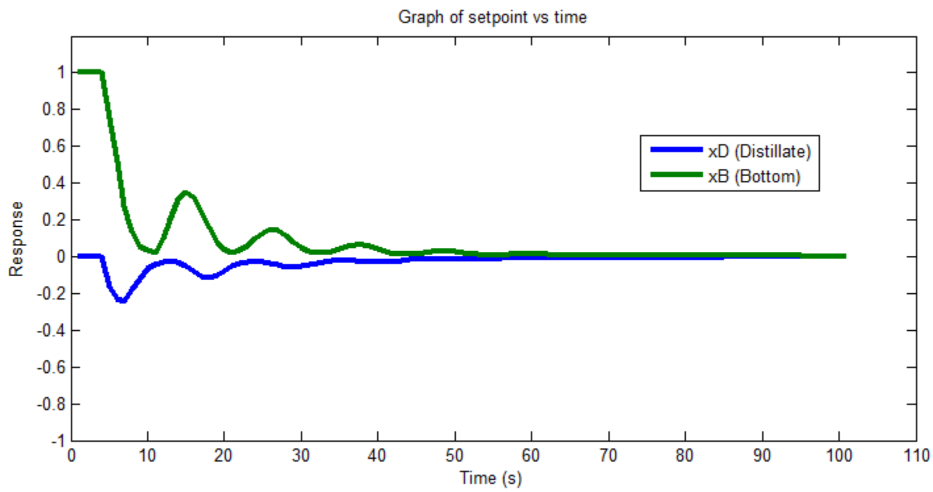


Figure 18: Response for disturbance rejection after tuning IMC based PI controller.

Based on the result shown from the disturbance rejection, the PID controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Table 6: Results for IAE, ISE and ITAE based on the response obtained from the IMC (PID) controller

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	IMC (PID)	xD	3.2588	1.7103	32.5844
					xB	4.8122	1.8683	84.4453
0	1	0	0		xD	2.3801	0.2686	66.0376
					xB	8.4232	5.0191	111.8322
0	0	1	0		xD	3.2588	1.7103	32.5844
					xB	4.8122	1.8683	84.4453
0	0	0	1		xD	2.3801	0.2686	66.0376
					xB	8.4232	5.0191	111.8322

Result

4.1.3 Tyreus Luyben controller settings on PI controller

Tuning settings:

Table 7: Tuning setting for TL PI controller

	K_c	τ_i	τ_D
X_D	0.6665	8.8	0
X_B	-0.1302	24.2	0

Result:

Set point tracking

Conditions

$x_{Dsp}\ from\ 0\ to\ 1$

$x_{Bsp}\ no\ changes$

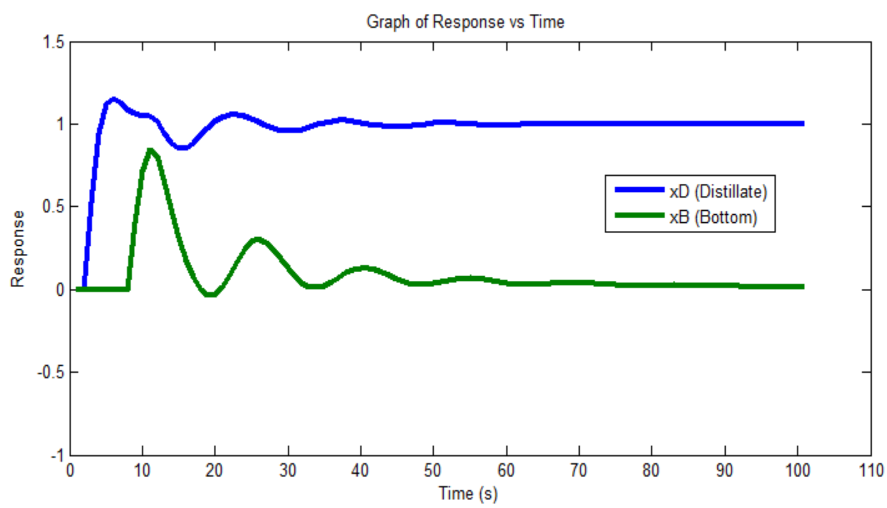


Figure 19: Response for set point tracking after tuning TL based PI controller.

Based on the result shown from the set-point tracking, the PI controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditions:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 1

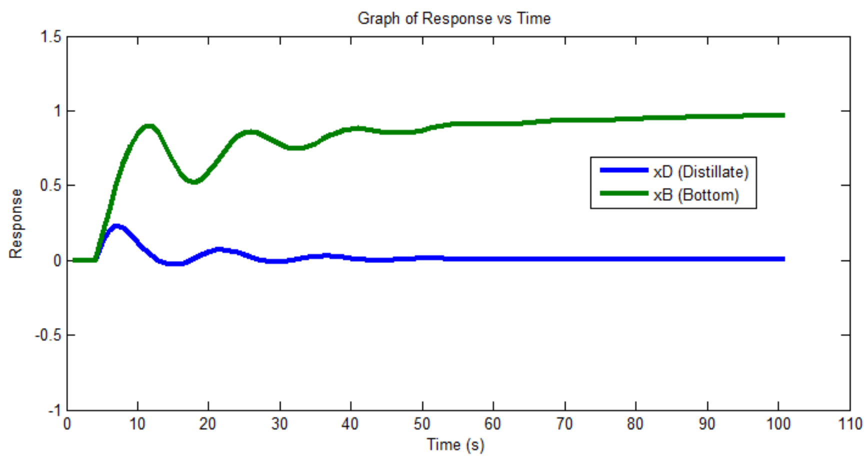


Figure 20: Response for set point tracking after tuning TL based PI controller.

Based on the result shown from the set-point tracking, the PI controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Disturbance Rejection

Conditons:

$F_1\ from\ 0\ to\ 1$

$F_2\ no\ changes$

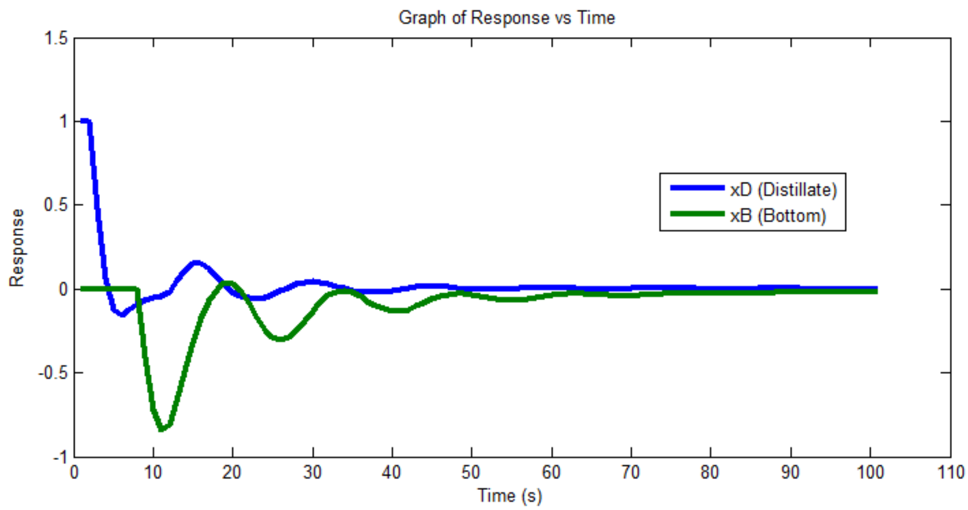


Figure 21: Response for disturbance rejection after tuning TL based PI controller

Based on the result shown from the disturbance rejection, the PI controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditons:

$F_1\ no\ changes$

$F_2 from\ 0\ to\ 1$

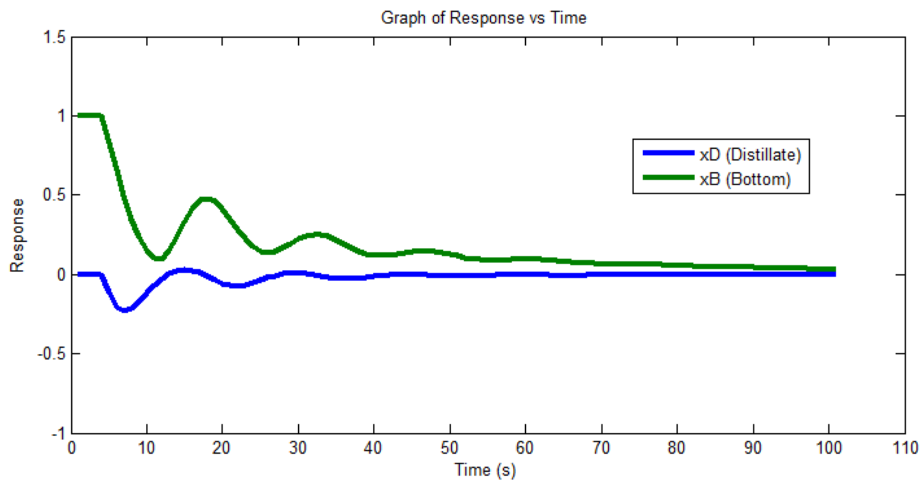


Figure 22: Response for disturbance rejection after tuning TL based PI controller

Based on the result shown from the disturbance rejection, the PI controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Table 8: Results for IAE, ISE and ITAE based on the response obtained from the TL (PI) controller

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	TL(PI)	xD	4.1612	1.9044	43.7118
					xB	9.4339	3.5034	263.0404
0	1	0	0		xD	2.1627	0.2377	43.6035
					xB	17.9522	7.5568	471.2276
0	0	1	0		xD	4.1612	1.9044	43.7118
					xB	9.4339	3.5034	263.0404
0	0	0	1		xD	2.1627	0.2377	43.6035
					xB	17.9522	7.5568	471.2276

4.1.4 Tyreus Luyben controller settings on PID controller

Tuning settings:

Table 9: Tuning setting for TL PID controller

	K_c	τ_i	τ_D
X_D	0.9675	8.8	0.635
X_B	-0.189	24.2	1.75

Results:

Set point tracking

Conditions:

x_{Dsp} *from* 0 *to* 1

x_{Bsp} *no changes*

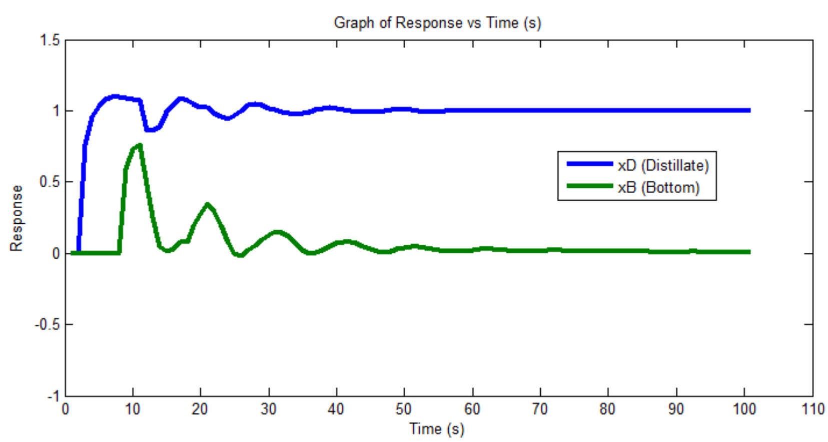


Figure 23: Response for set point tracking after tuning TL based PID controller.

Based on the result shown from the set-point tracking, the PID controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditions:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 1

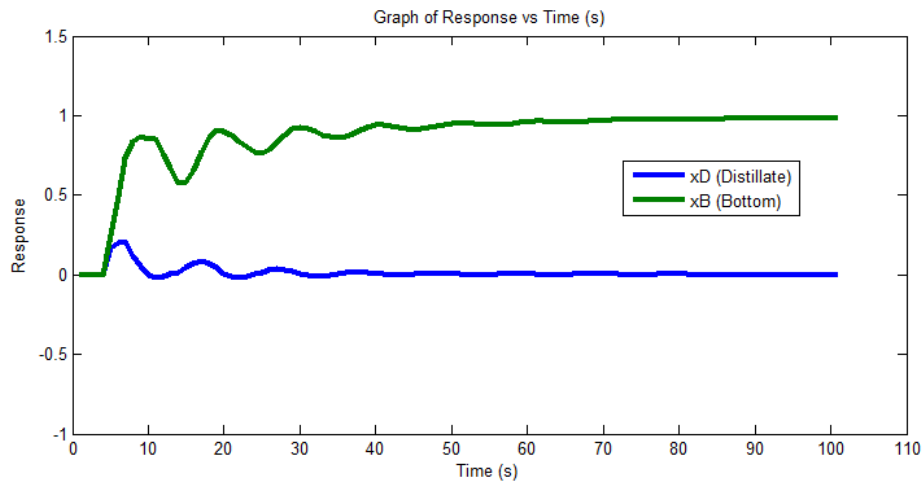


Figure 24: Response for set point tracking after tuning TL based PID controller.

Based on the result shown from the set-point tracking, the PID controller tries to make sure that the value of top and bottom is as per set point. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Disturbance Rejection

Conditons:

$F_1\ from\ 0\ to\ 1$

$F_2\ no\ changes$

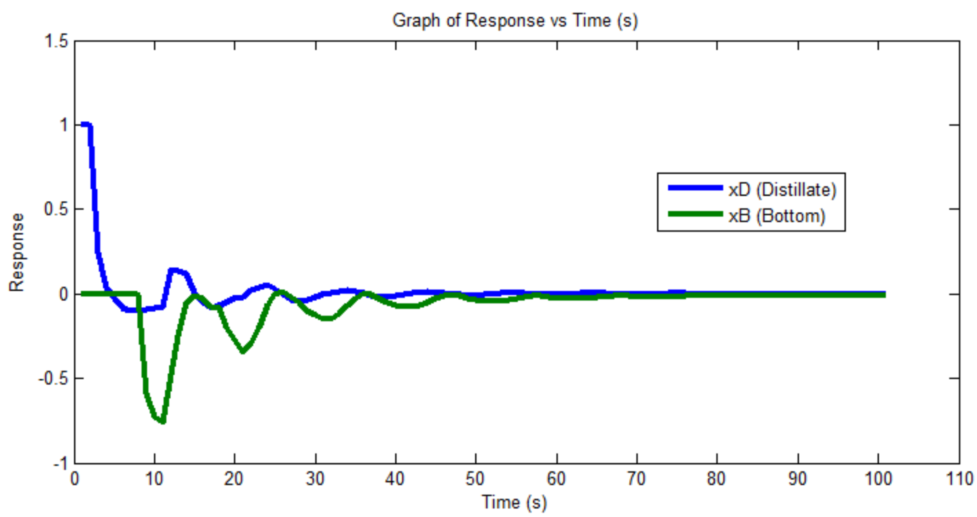


Figure 25: Response for disturbance rejection after tuning TL based PID controller.

Based on the result shown from the disturbance rejection, the PID controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Conditons:

F_1 *no changes*

F_2 *from* 0 *to* 1

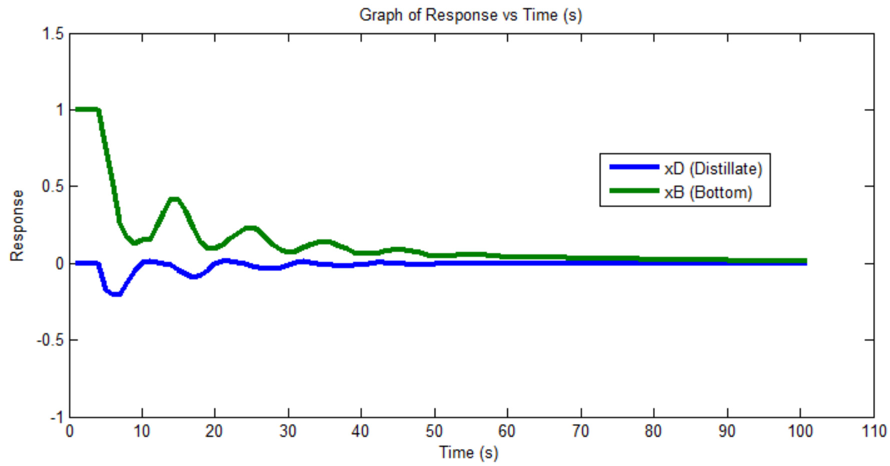


Figure 26: Response for disturbance rejection after tuning TL based PID controller.

Based on the result shown from the disturbance rejection, the PID controller tries to make sure that the value of top and bottom is as per set point despite the change in the disturbance. Therefore, the response shows that there's an offset at first but eventually as the time reaches around 100 minutes the response reaches the desired value and reaches the steady state.

Table 10: Results for IAE, ISE and ITAE based on the response obtained from the TL (PID) Controller

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	TL(PID)	xD	3.5992	1.6908	35.1313
					xB	6.6252	2.2659	162.7373
0	1	0	0		xD	1.5522	0.16	104.153
					xB	12.8061	5.7096	138.6269
0	0	1	0		xD	3.5992	1.6908	35.1313
					xB	6.6252	2.2659	162.7373
0	0	0	1		xD	1.5522	0.16	104.153
					xB	12.8061	5.7096	138.6269

4.1.5 Ziegler Nichols controller settings on PI controller

Tuning settings:

Table 11: Tuning setting for ZN PI controller

	K_c	τ_i	τ_D
X_D	0.9675	3.3333	0
X_B	-0.189	9.167	0

Result:

Set point tracking

Conditions

$x_{Dsp}\ from\ 0\ to\ 1$

$x_{Bsp}\ no\ changes$

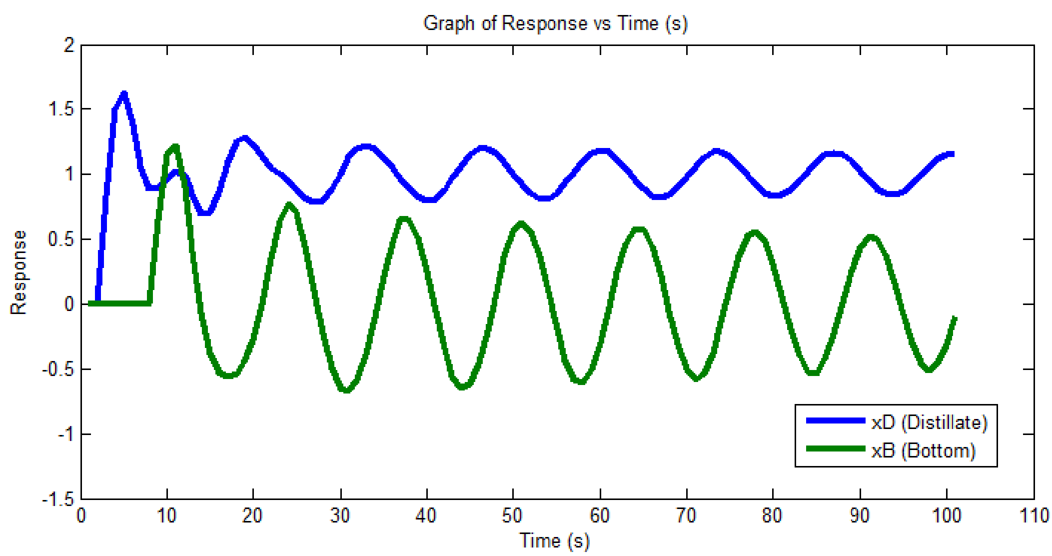


Figure 27: Response for set point tracking after tuning ZN based PI controller.

Based on the result of tuning for set point tracking, the PI controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore the result shows that the tuning fails on set-point tracking test.

Conditions:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 1

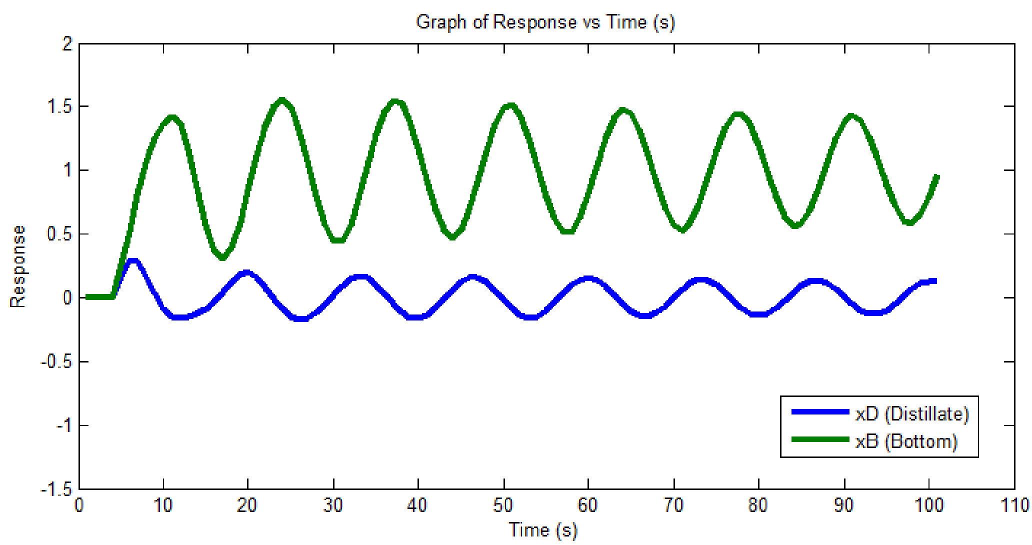


Figure 28: Response for set point tracking after tuning ZN based PI controller.

Based on the result of tuning for set point tracking, the PI controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore the result shows that the tuning fails on set-point tracking test.

Disturbance Rejection

Conditons:

$F_1\ from\ 0\ to\ 1$

$F_2\ no\ changes$

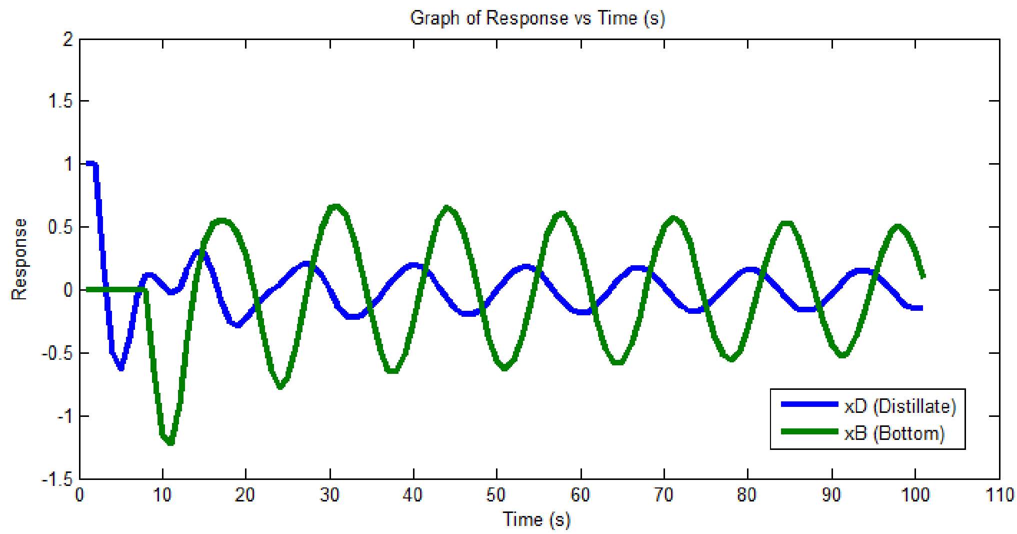


Figure 29: Response for disturbance rejection after tuning ZN based PI controller

Based on the result of tuning for disturbance rejection, the PI controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore, the result shows that the tuning fails on the disturbance rejection test.

Conditons:

$F_1\ no\ changes$

$F_2 from\ 0\ to\ 1$

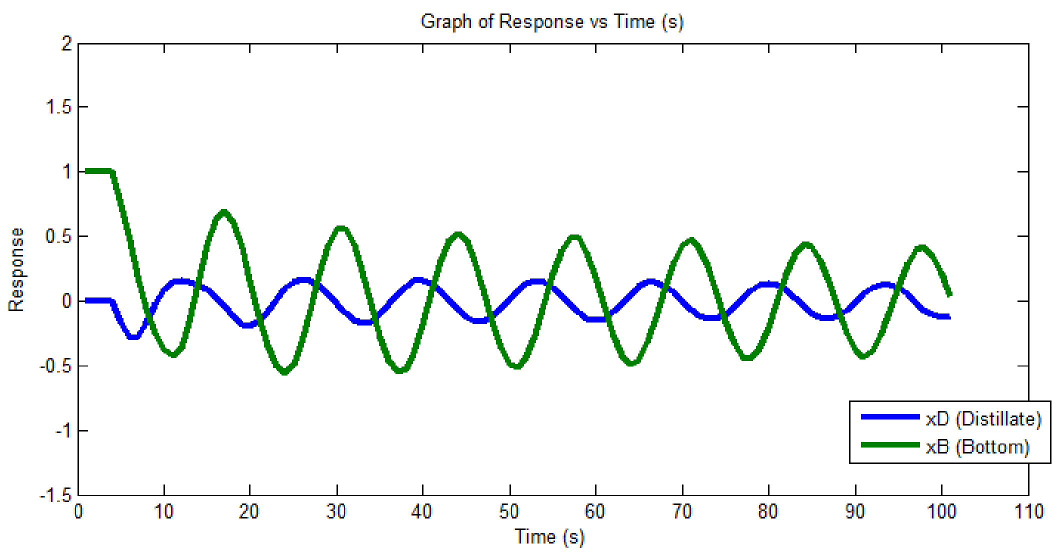


Figure 30: Response for disturbance rejection after tuning ZN based PI controller

Based on the result of tuning for disturbance rejection, the PI controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore, the result shows that the tuning fails on the disturbance rejection test.

Table 12: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	ZN(PI)	xD	14.6800	4.17	585.5813
					xB	38.3909	20.73	1.89E+03
0	1	0	0		xD	10.1292	1.3668	476.4032
					xB	35.0708	16.5198	1.54E+03
0	0	1	0		xD	14.6800	4.17	585.5813
					xB	38.3909	20.73	1.89E+03
0	0	0	1		xD	10.1292	1.3668	476.4032
					xB	35.0708	16.5198	1.54E+03

4.1.6 Ziegler Nichols controller settings on PI controller

Tuning settings:

Table 13: Tuning setting for ZN PID controller

	K_c	τ_i	τ_D
X_D	1.29	2	0.5
X_B	-0.252	5.5	1.375

Result:

Set point tracking

Conditions

$x_{Dsp}\ from\ 0\ to\ 1$

$x_{Bsp}\ no\ changes$

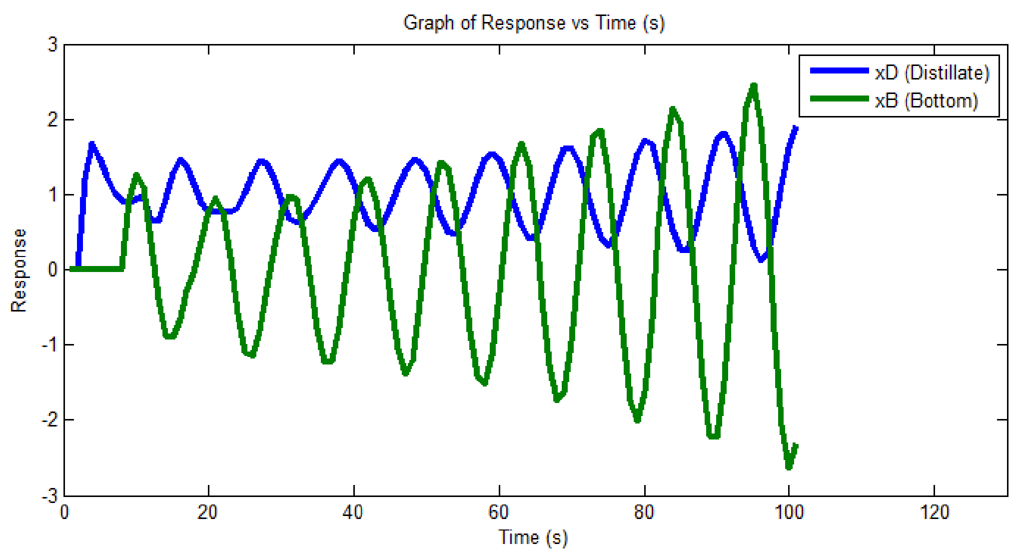


Figure 31: Response for set point tracking after tuning TL based PID controller.

Based on the result of tuning for set point tracking, the PID controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore the result shows that the tuning fails on set-point tracking test.

Conditions:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 1

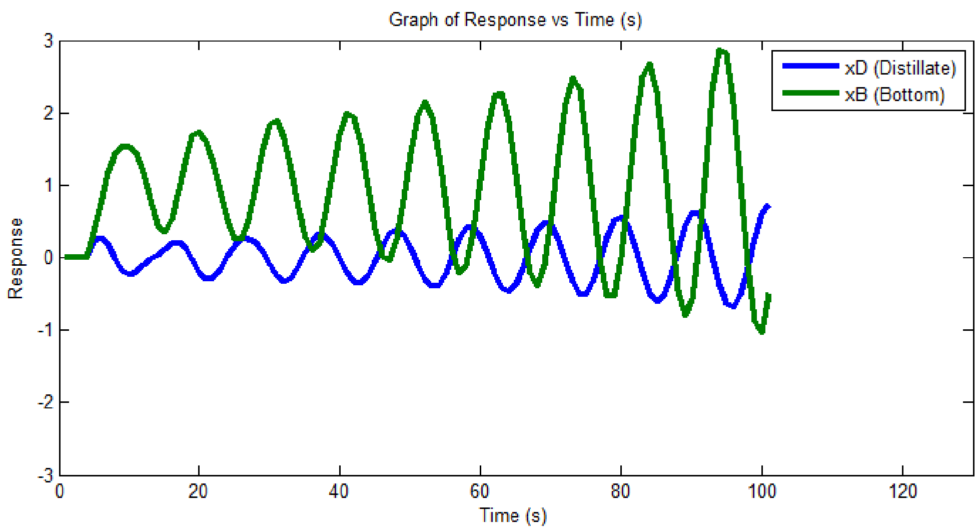


Figure 32: Response for set point tracking after tuning TL based PID controller.

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Based on the result of tuning for set point tracking, the PID controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore the result shows that the tuning fails on set-point tracking test.

Disturbance Rejection

Conditons:

F_1 *from* 0 *to* 1

F_2 *no changes*

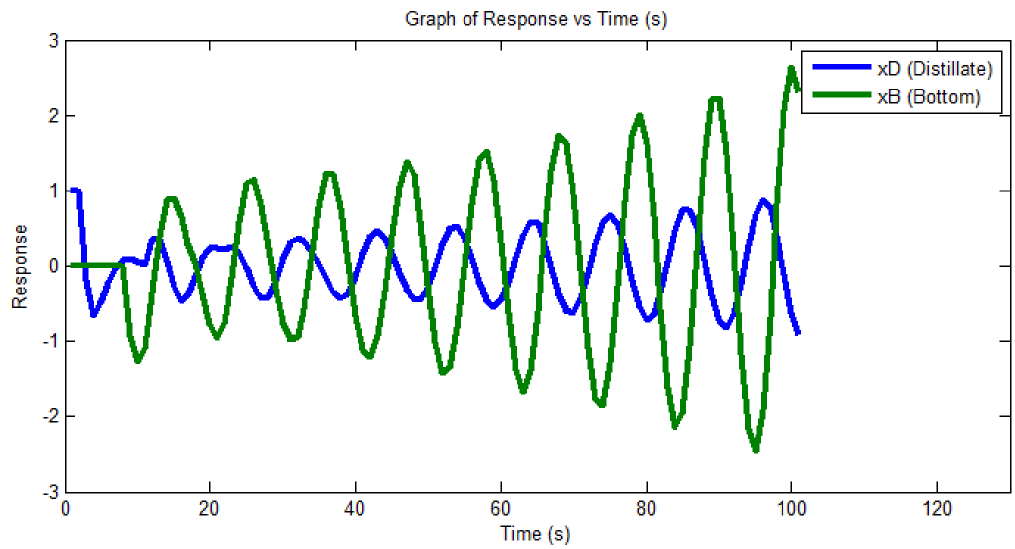

Figure 33: Response for disturbance rejection after tuning ZN based PID controller

Based on the result of tuning for disturbance rejection, the PID controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore, the result shows that the tuning fails on the disturbance rejection test.

Conditons:

F_1 *no changes*

F_2 *from* 0 *to* 1

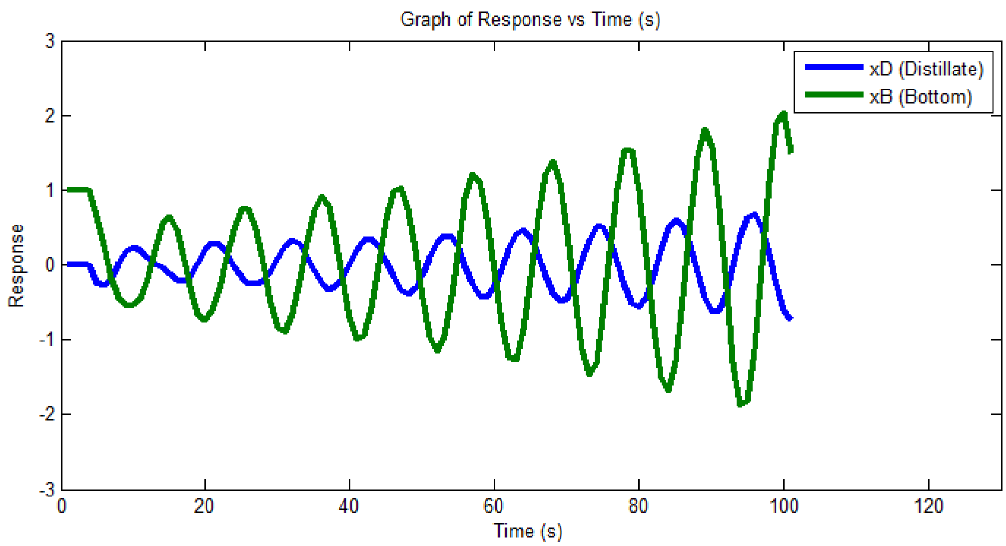

Figure 34: Response for disturbance rejection after tuning ZN based PID controller.

Based on the result of tuning for disturbance rejection, the PID controller never reaches its set point due to continuous oscillation. The result shows a continuous oscillation due to the on-line tuning using ZN method. Therefore, the result shows that the tuning fails on the disturbance rejection test.

Table 14: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

Type of input				Tuning Setting	Result	IAE	ISE	ITAE
xD	xB	F1	F2					
1	0	0	0	ZN (PID)	xD	36.1948	18.359	2.06E+03
					xB	95.4167	133.7117	5.92E+03
0	1	0	0		xD	26.4874	10.0522	1.62E+03
					xB	78.6223	85.206	4.65E+03
0	0	1	0		xD	36.1948	18.359	2.06E+03
					xB	95.4167	133.7117	5.92E+03
0	0	0	1		xD	26.4874	10.0522	1.62E+03
					xB	78.6223	85.206	4.65E+03

4.2. Results for MPC Controller

For the result of MPC controllers the prediction horizon, controlled horizon, rate weight and also the change in weight is altered and the response is taken for each and every value for each parameters. The optimum parameter setting for MPC controller based on the heuristic method is:

Prediction Horizon (Np): 45

Controller Horizon (Nc): 38

Weight: 0

Rate Weight: 0.1

Control Interval: 1 minute

Basically only the set point tracking test is conducted for this type of controller as it is assumed the disturbance variable is neglected. The results and response for the following settings are shown in the next section

4.2.1. Prediction Horizon (Np)

Tuning setting

Table 15: Tuning setting for the change in prediction horizon

Np	51	48	45	42	39
Nc	38	38	38	38	38
Weight	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1

Response:

Conditons:

x_{Dsp} *from* 0 *to* 0.5

x_{Bsp} *no changes*

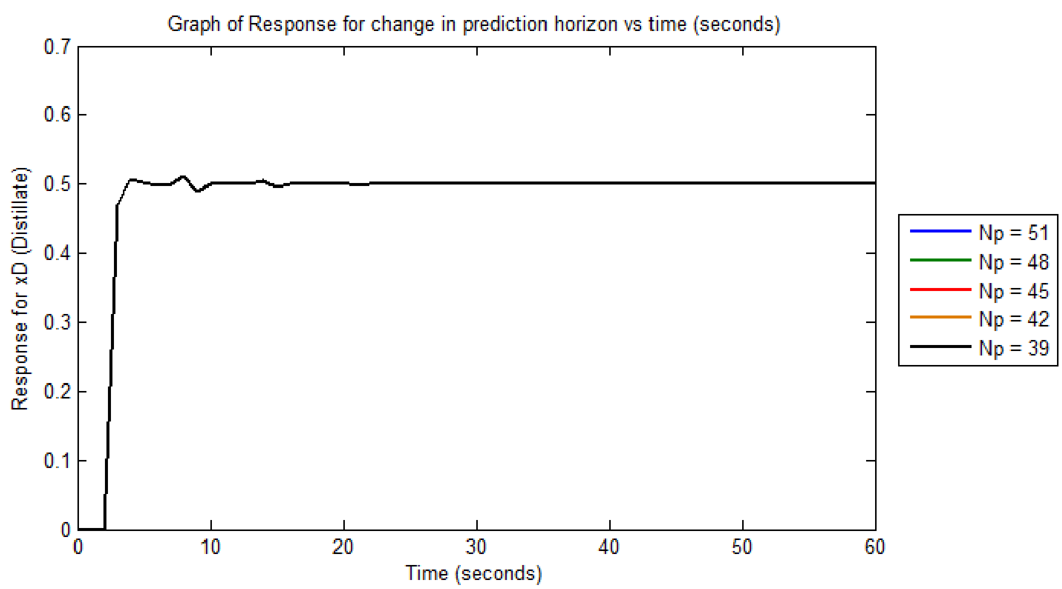

Figure 35: Response for set point tracking on the distillate product after tuning on MPC controller

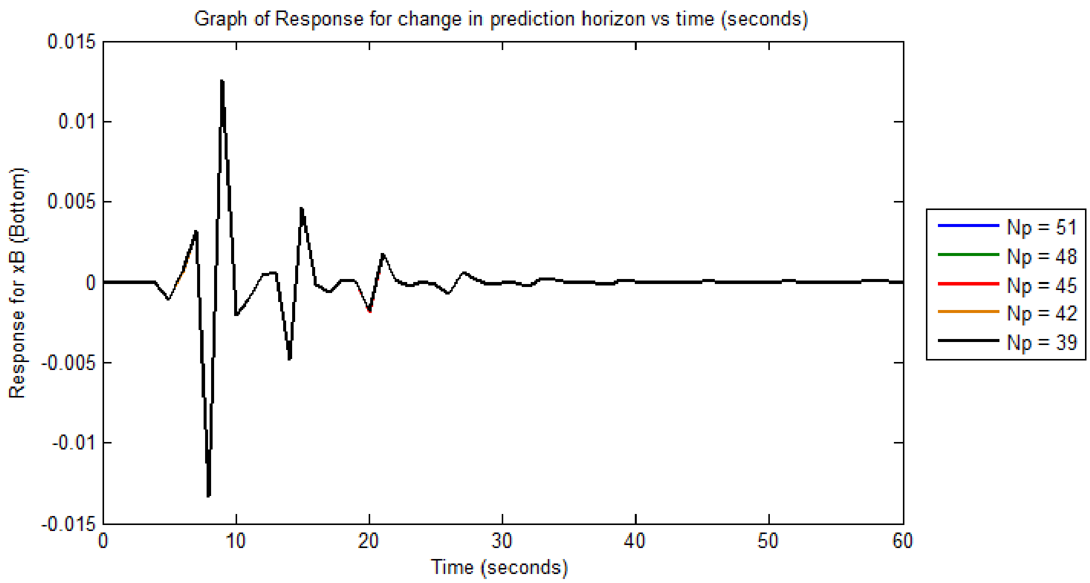

Figure 36 Response for set point tracking on the bottom product after tuning on MPC controller

Conditons:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 0.5

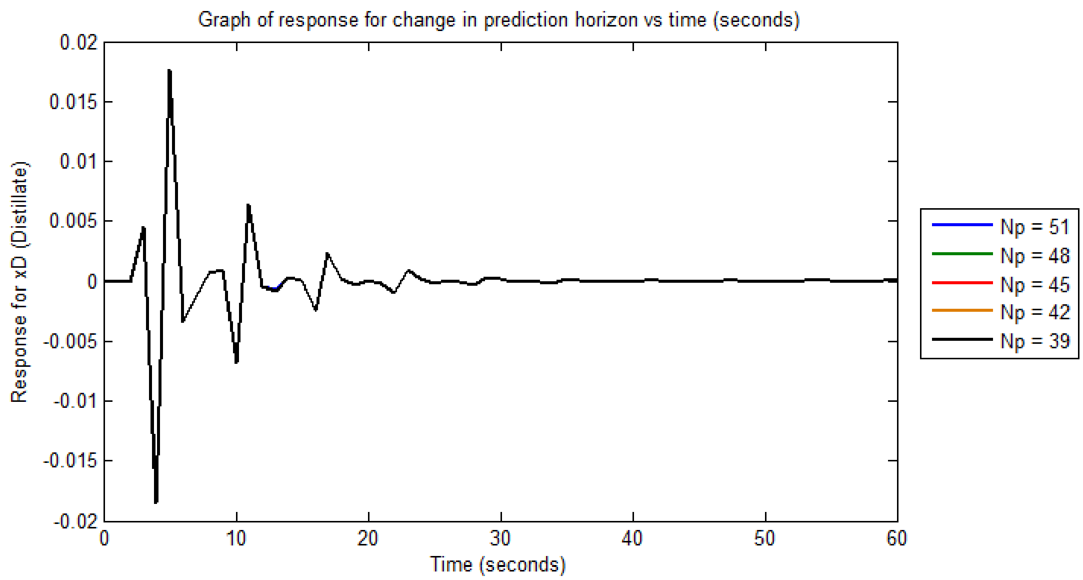

Figure 37: Response for set point tracking on the distillate product after tuning on MPC controller

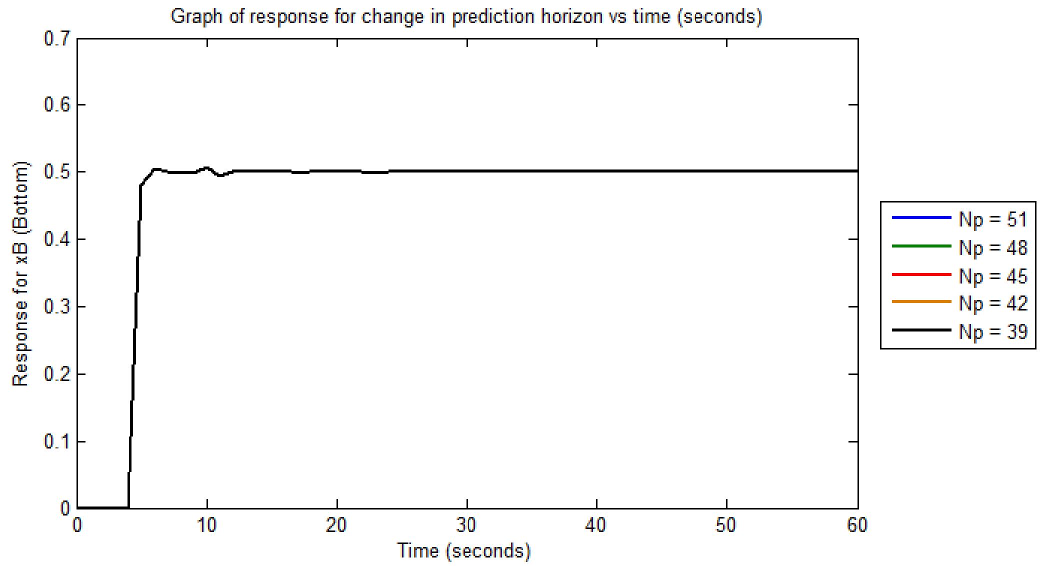

Figure 38: Response for set point tracking on the bottom product after tuning on MPC controller

Table 16: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

xD			0.5			xB			0		
Np	51	48	45	42	39	**Np**	51.0	48.0	45.0	42.0	39.0
Nc	38	38	38	38	38	**Nc**	38.0	38.0	38.0	38.0	38.0
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	1.338	1.338	1.338	1.337	1.337	**IAE**	0.053	0.053	0.053	0.053	0.053
ISE	0.626	0.626	0.626	0.626	0.626	**ISE**	0.000	0.000	0.000	0.000	0.000
ITAE	2.213	2.213	2.213	2.213	2.215	**ITAE**	0.633	0.633	0.633	0.633	0.633
xD			0			**xB**			0.5		
Np	51	48	45	42	39	**Np**	51	48	45	42	39
Nc	38	38	38	38	38	**Nc**	38	38	38	38	38
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	0.072	0.072	0.072	0.071	0.071	**IAE**	2.303	2.303	2.303	2.303	2.303
ISE	0.001	0.001	0.001	0.001	0.001	**ISE**	1.126	1.126	1.126	1.126	1.126
ITAE	0.589	0.589	0.589	0.587	0.587	**ITAE**	5.543	5.543	5.543	5.541	5.541

Based on the graph of tuning for set-point tracking, the response for MPC controller is basically the same after an increment from the optimum value which is Np = 45. Table 15 shows that the integral absolute error, integral squared error and also the integral time absolute error shows a small amount of error. Hence, based on the result for the error criteria the response for the tuning is considered good because it reaches the desired set point for both distillate and bottom when the set point is set to 0.5 after around 30-40 seconds. However, the valve may be damaged after a long period of time due to the fast response of the controller.

4.2.2. Controlled Horizon (Nc)

Tuning setting

Table 17: Tuning setting for the change in controlled horizon

Np	45	45	45	45	45
Nc	38	34	30	26	22
Weight	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1

Response:

Conditons:

$x_{Dsp}\ from\ 0\ to\ 0.5$

$x_{Bsp}\ no\ changes$

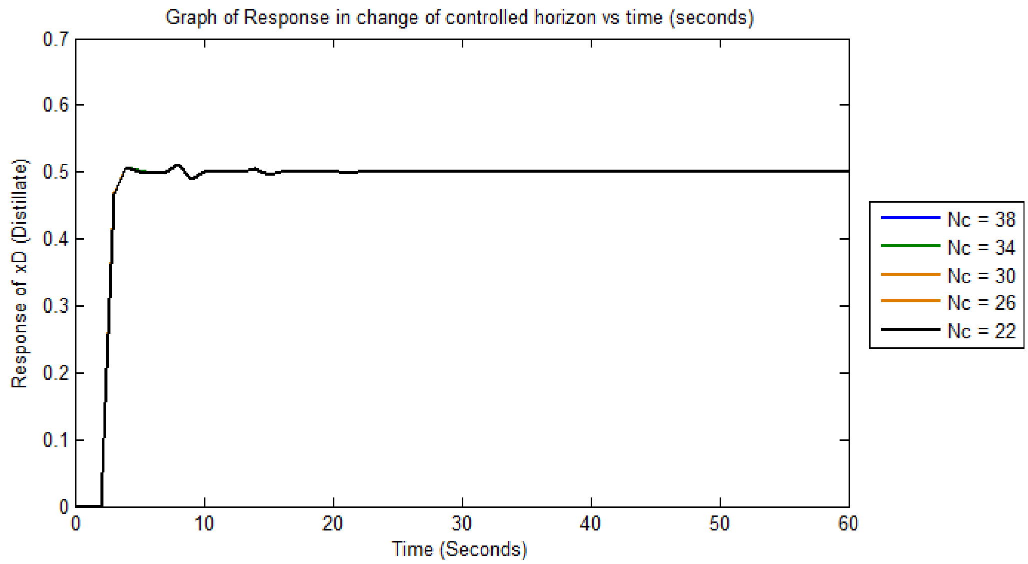

Figure 39: Response for set point tracking on the distillate product after tuning on MPC controller

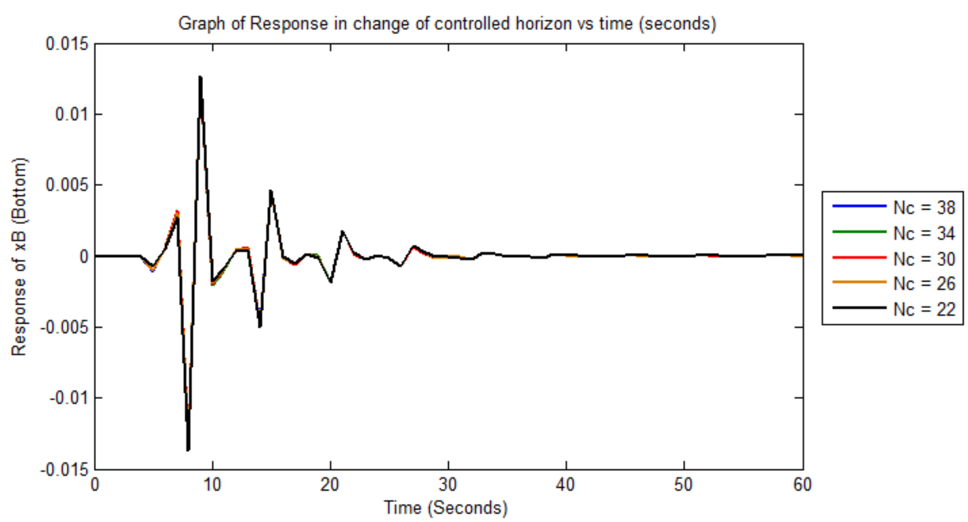

Figure 40: Response for set point tracking on the bottom product after tuning on MPC controller

Conditons:

x_{Dsp} $no\ changes$

x_{Bsp} $0\ to\ 0.5$

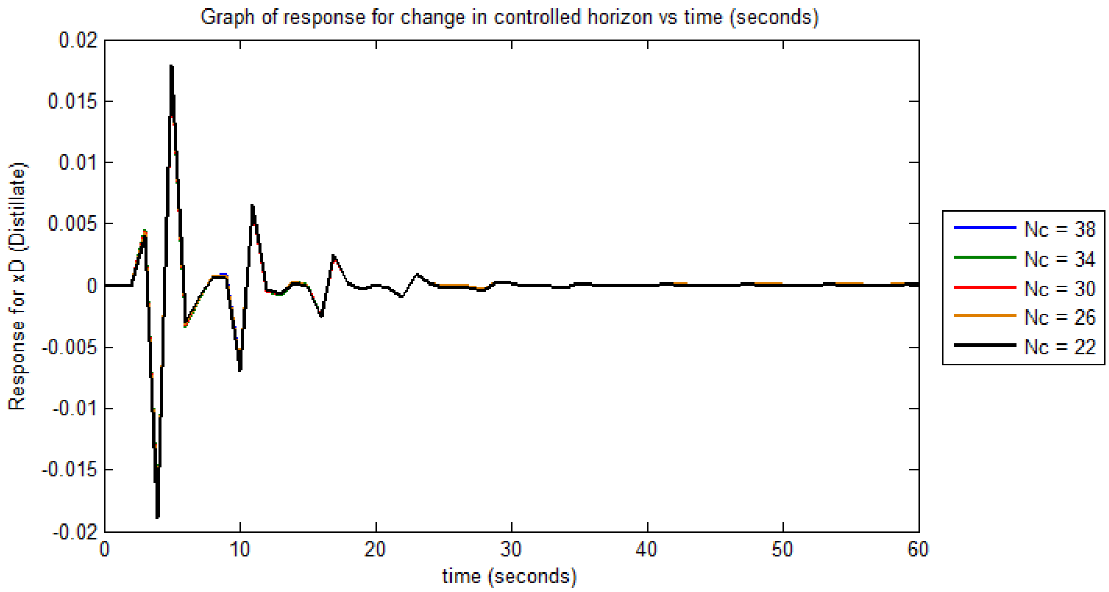

Figure 41: Response for set point tracking on the distillate product after tuning on MPC controller

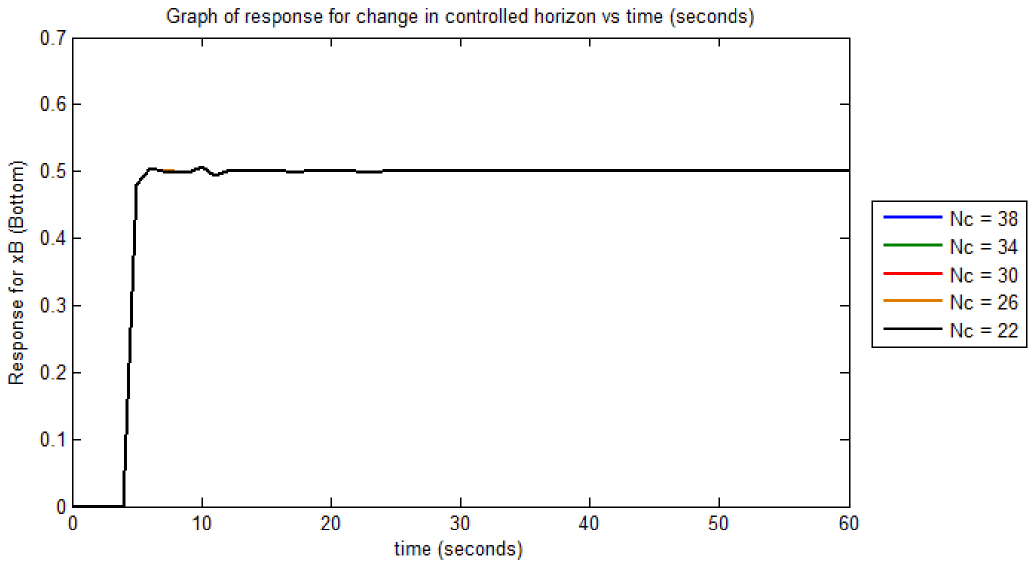

Figure 42: Response for set point tracking on the bottom product after tuning on MPC controller

Table 18: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

xD			0.5			xB			0		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	34	30	26	22	**Nc**	38	34	30	26	22
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	1.338	1.338	1.338	1.337	1.337	**IAE**	0.053	0.053	0.052	0.052	0.052
ISE	0.626	0.626	0.626	0.626	0.626	**ISE**	0.000	0.000	0.000	0.000	0.000
ITAE	2.213	2.214	2.213	2.213	2.215	**ITAE**	0.633	0.633	0.633	0.631	0.629
xD			0			**xB**			0.5		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	34	30	26	22	**Nc**	38	34	30	26	22
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	0.072	0.072	0.072	0.071	0.071	**IAE**	2.303	2.303	2.303	2.303	2.303
ISE	0.001	0.001	0.001	0.001	0.001	**ISE**	1.126	1.126	1.126	1.126	1.126
ITAE	0.589	0.589	0.589	0.587	0.587	**ITAE**	5.543	5.543	5.543	5.541	5.541

Based on the graph of tuning for set-point tracking, the response for MPC controller is basically the same after an increment from the optimum value which is Nc = 38. Table 17 shows that the integral absolute error, integral squared error and also the integral time absolute error shows a small amount of error. Hence, based on the result for the error criteria the response for the tuning is considered good because it reaches the desired set point for both distillate and bottom when the set point is set to 0.5 after around 30-40 seconds. However, the valve may be damaged after a long period of time due to the fast response of the controller.

4.2.3. Weight Tuning

Tuning setting

Table 19: Tuning setting for the change in weight

Np	45	45	45	45	45
Nc	38	38	38	38	38
Weight	0	2	4	6	8
Rate Weight	0.1	0.1	0.1	0.1	0.1

Response:

Conditons:

$x_{Dsp}\ from\ 0\ to\ 0.5$

$x_{Bsp}\ no\ changes$

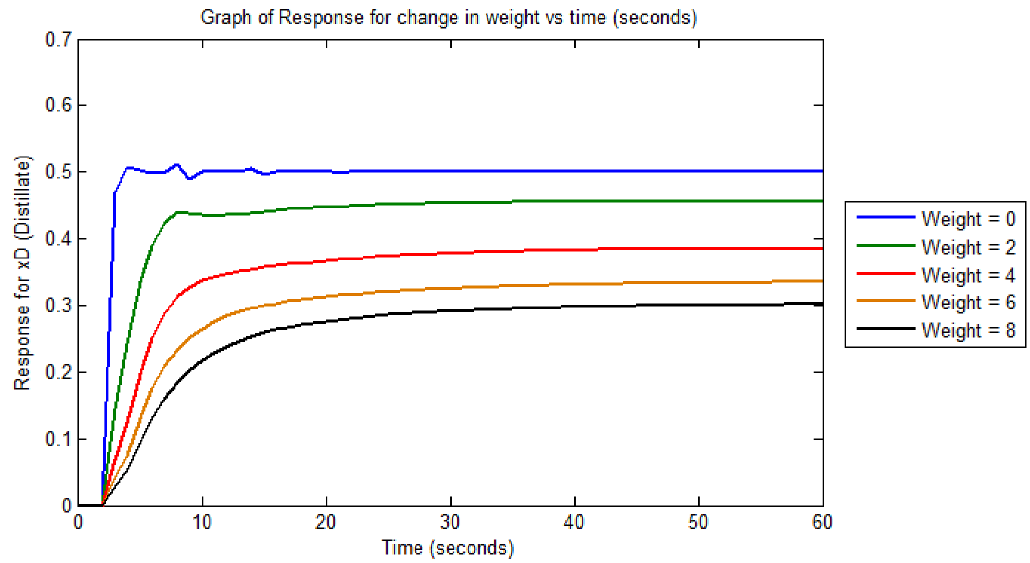

Figure 43: Response for set point tracking on the distillate product after tuning on MPC controller

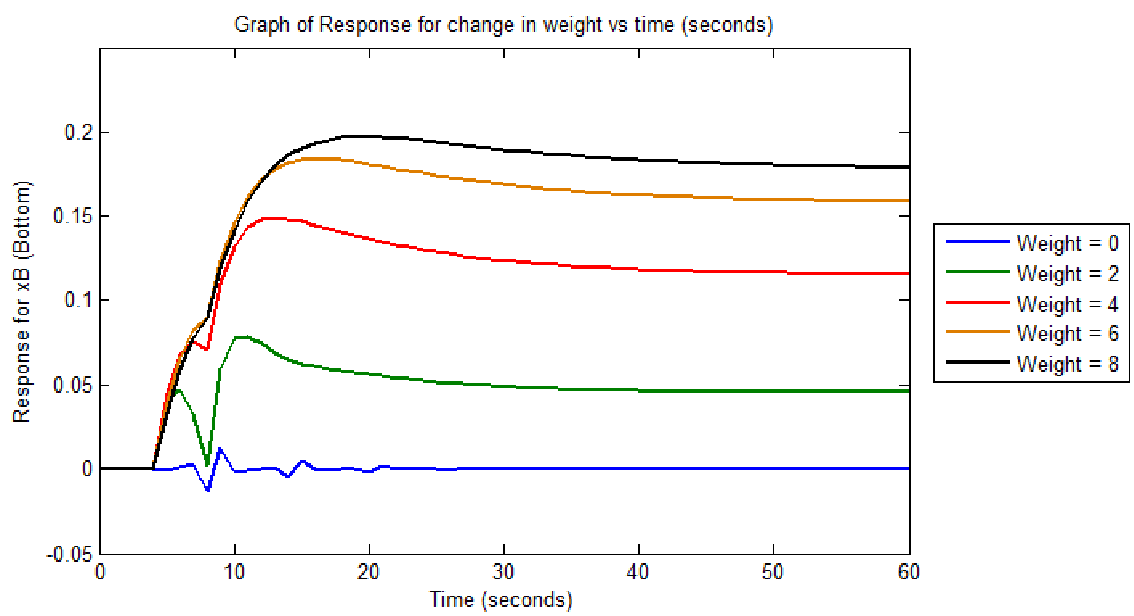

Figure 44: Response for set point tracking on the bottom product after tuning on MPC controller

Conditons:

x_{Dsp} $no\ changes$

x_{Bsp} $0\ to\ 0.5$

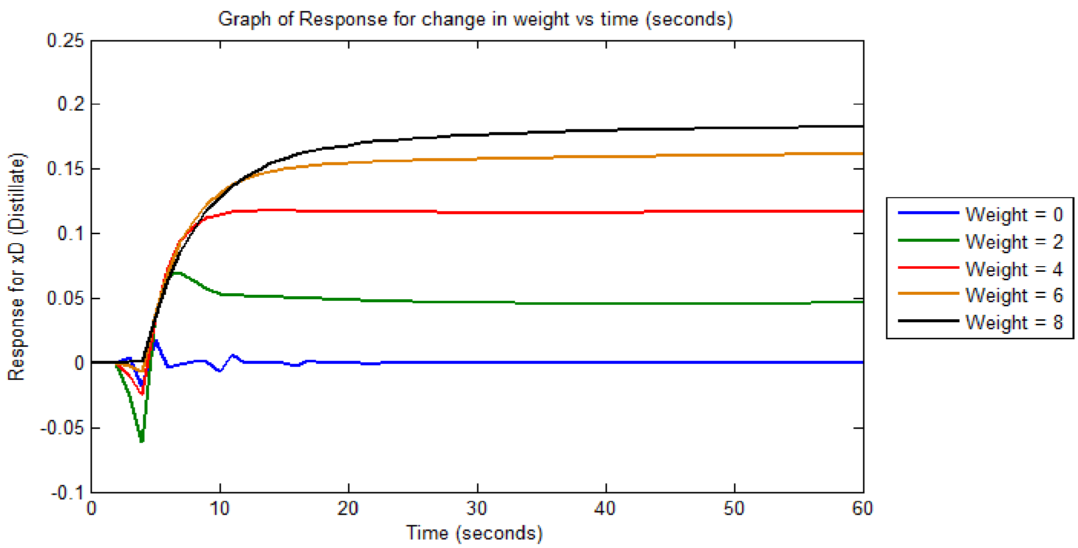

Figure 45: Response for set point tracking on the distillate product after tuning on MPC controller

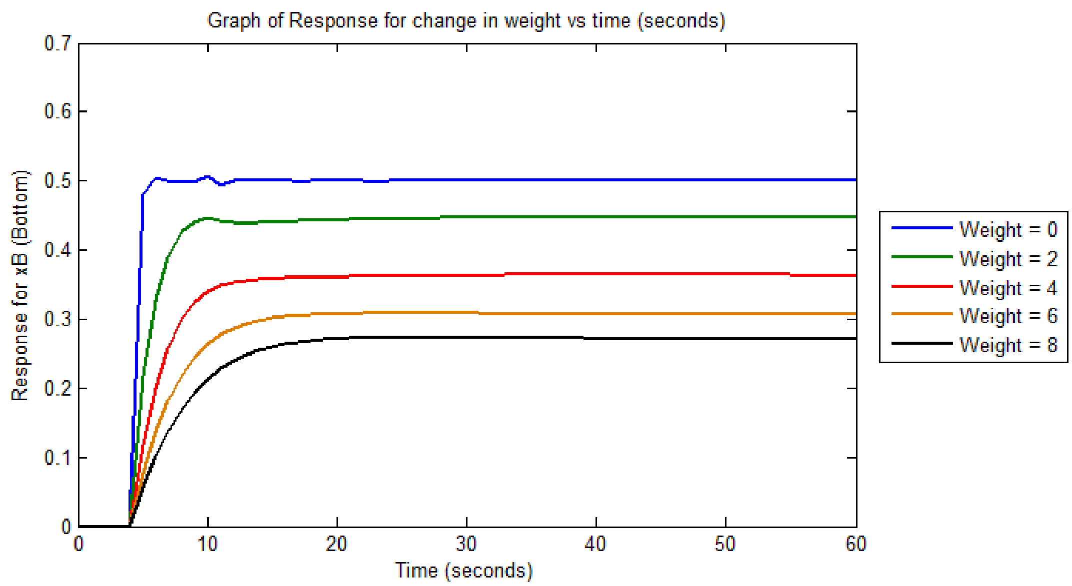

Figure 46: Response for set point tracking on the bottom product after tuning on MPC controller

Table 20: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

xD		0.5			xB			0		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	38	38	38	38	**Nc**	38	38	38	38	38
Weight	0	2	4	6	8	**Weight**	0	2	4	6	8
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	1.338	4.792	9.478	12.639	14.710	**IAE**	0.053	2.792	6.708	8.851	9.701
ISE	0.626	0.993	2.009	3.095	3.988	**ISE**	0.000	0.147	0.831	1.454	1.758
ITAE	2.213	87.878	222.716	317.480	380.037	**ITAE**	0.633	86.876	215.918	291.863	325.513
xD			0			**xB**			0.5		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	38	38	38	38	**Nc**	38	38	38	38	38
Weight	0	2	4	6	8	**Weight**	0	2	4	6	8
Rate Weight	0.1	0.1	0.1	0.1	0.1	**Rate Weight**	0.1	0.1	0.1	0.1	0.1
IAE	0.072	2.768	6.344	8.342	9.160	**IAE**	2.303	5.703	10.539	13.767	15.820
ISE	0.001	0.135	0.726	1.280	1.561	**ISE**	1.126	1.406	2.459	3.616	4.547
ITAE	0.589	84.089	207.817	281.342	314.385	**ITAE**	5.543	103.724	254.460	356.621	420.942

Based on the graph of tuning for set-point tracking, the error for response of the bottom and distillate product increases as the weight tuning increases. Figure 42, 43, 44 and 45 shows that the response meets the set-point only when the weight tuning equals to 0. For the weight tuning equals to 2,4,6,8 the product of distillate and the bottom doesn't even reach the set point. Table 19 shows the result for IAE, ISE and ITAE based on the response obtain from the setting and it shows that as the weight tuning increases the margin of error increases. Based on the result above, the response for weight tuning more than zero fails the set-point tracking test.

4.2.4. Rate Weight Tuning

Tuning setting

Table 21: Tuning setting for the change in weight

Np	45	45	45	45	45
Nc	38	38	38	38	38
Weight	0	0	0	0	0
Rate Weight	100	10	1	0.1	0.01

Response:

Conditons:

$x_{Dsp}\ from\ 0\ to\ 0.5$

$x_{Bsp}\ no\ changes$

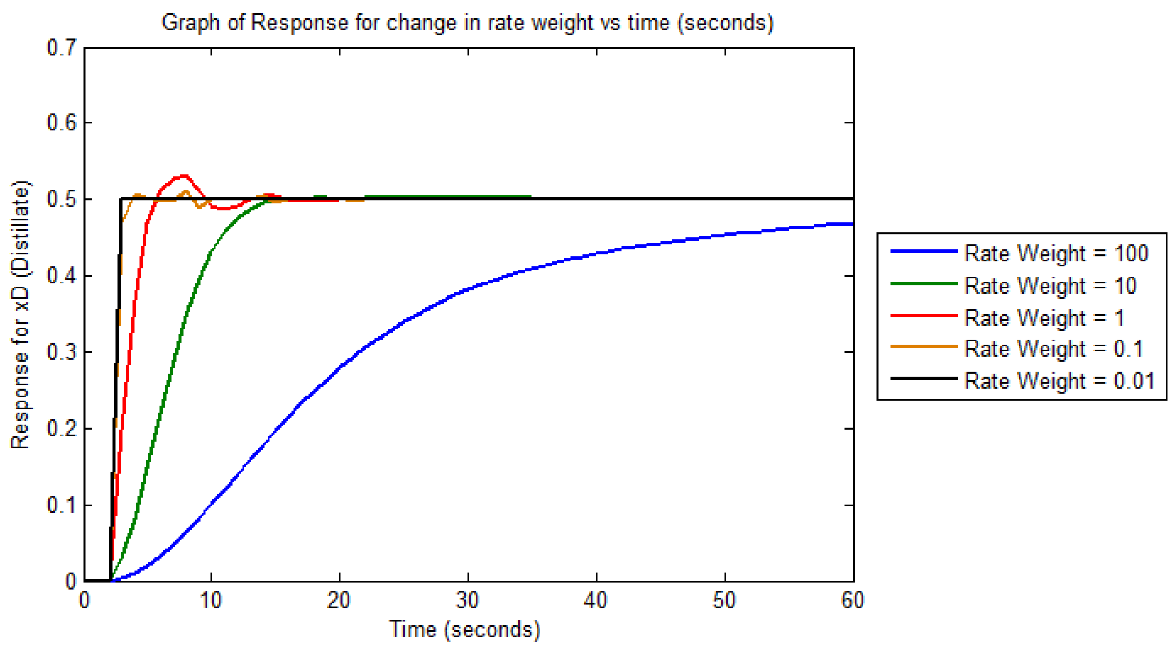

Figure 47: Response for set point tracking on the distillate product after tuning on MPC controller

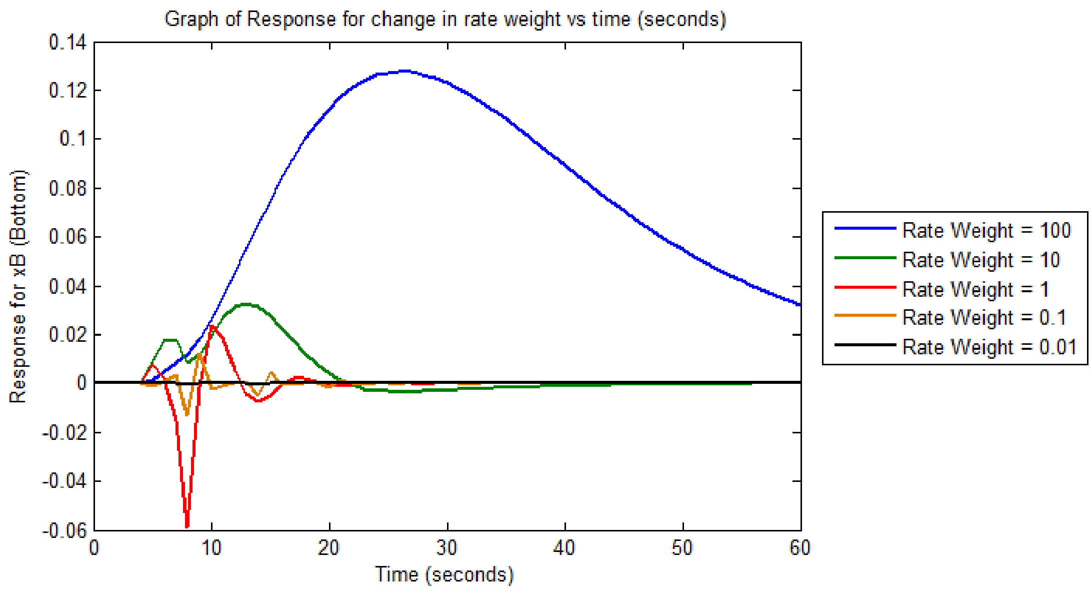

Figure 48: Response for set point tracking on the bottom product after tuning on MPC controller

Conditons:

x_{Dsp} *no changes*

x_{Bsp} 0 *to* 0.5

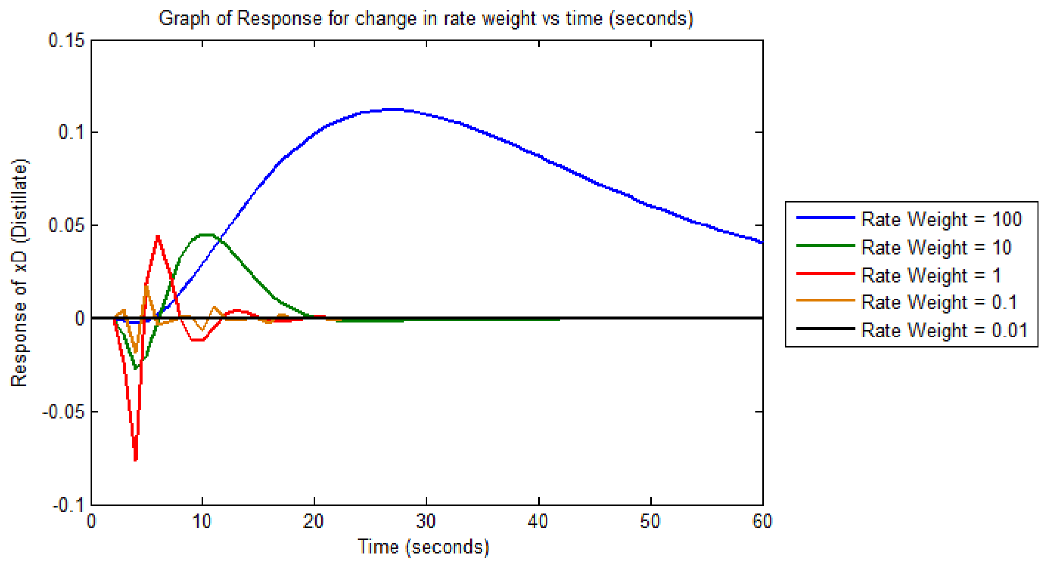

Figure 49: Response for set point tracking on the bottom product after tuning on MPC controller

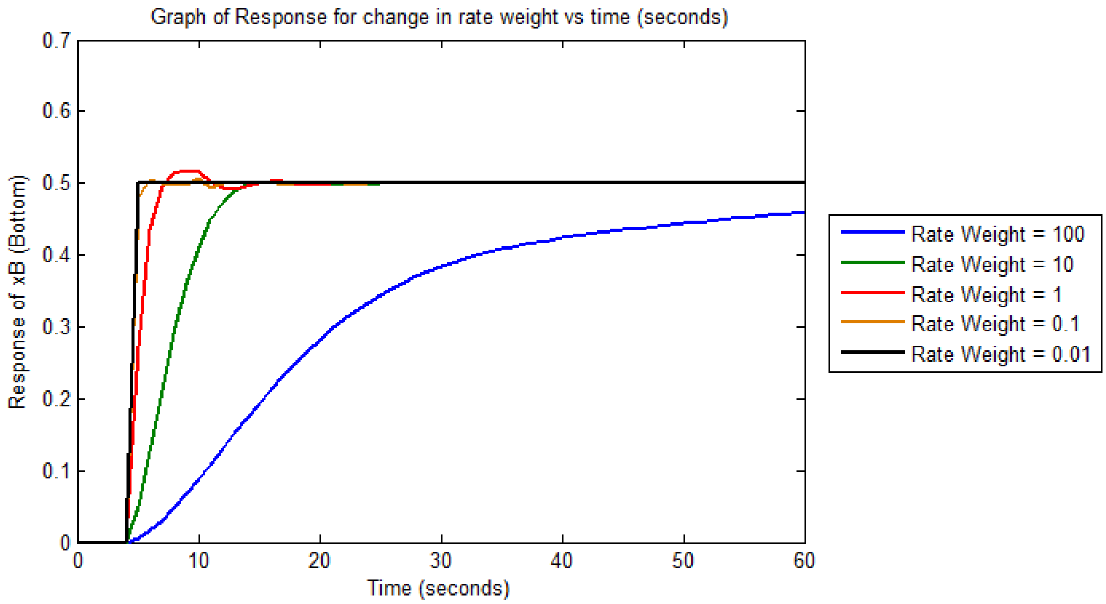

Figure 50: Response for set point tracking on the bottom product after tuning on MPC controller

Table 22: Results for IAE, ISE and ITAE based on the response obtained from the controllers settings

ITAE	0.589	84.089	207.817	281.342	314.385	**ITAE**	5.543	103.724	254.460	356.621	420.942
xD			0.5			**xB**			0		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	38	38	38	38	**Nc**	38	38	38	38	38
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	100	10	1	0.1	0.01	**Rate Weight**	100	10	1	0.1	0.01
IAE	11.262	3.442	1.844	1.338	1.252	**IAE**	4.239	0.350	0.159	0.053	0.001
ISE	3.586	1.309	0.738	0.626	0.625	**ISE**	0.402	0.007	0.005	0.000	0.000
ITAE	185.320	14.889	4.289	2.213	1.521	**ITAE**	135.530	5.331	1.569	0.633	0.019
xD			0			**xB**			0.5		
Np	45	45	45	45	45	**Np**	45	45	45	45	45
Nc	38	38	38	38	38	**Nc**	38	38	38	38	38
Weight	0	0	0	0	0	**Weight**	0	0	0	0	0
Rate Weight	100	10	1	0.1	0.01	**Rate Weight**	100	10	1	0.1	0.01
IAE	4.076	0.415	0.234	0.072	0.002	**IAE**	11.547	3.921	2.621	2.303	2.251
ISE	0.352	0.012	0.010	0.001	0.000	**ISE**	3.710	1.626	1.181	1.126	1.125
ITAE	133.873	4.829	1.445	0.589	0.019	**ITAE**	194.886	17.247	7.394	5.543	5.016

Based on the graph of tuning for set-point tracking, the error for response of the bottom and distillate product decreases as the rate weight tuning decreases. Figure 46, 47, 48 and 49 shows that the response doesn't meet the set-point only when the rate weight tuning equals to 100. For the rate weight tuning equals to 10, 1, 0.1, 0.01 the product of distillate and the bottom reaches the set point but at a different rate. As the value of rate weight decreases the faster the controller reaches its set point. Table 21 shows the result for IAE, ISE and ITAE based on the response obtain from the setting and it shows that as the rate weight tuning decreases the margin of error decreases. Based on the result above, the response for rate weight tuning more than 10 fails the set-point tracking test.

4.3. Discussion

Based on the results obtained for PID controller for Internal Model Controller (IMC), Ziegler Nichols (ZN) and Tyreus Luyben (TL), it is proven that TL and IMC provides a convincing result and the response shown for set point tracking and disturbance rejection gives a good response. Meanwhile, the results of set point tracking and disturbance rejection for ZN method proves that ZN fails the set point tracking test and also the disturbance rejection test as it cannot reach the set point desired. In comparison on the IAE, ISE and ITAE, the result for IMC provide a better result as compared to TL and ZN. Therefore, the best result for PID controller for tuning of distillation column is IMC PID controller.

Based on the results obtained for MPC controller the increment and decrement of the prediction horizon and the controlled horizon doesn’t make a huge difference to the response of the controller as the difference in result is not significant although a smaller value of prediction horizon and controlled horizon do produce a smaller error. For the weight tuning, as the weight increases the error calculated increases. Therefore, for the weight tuning a smaller value is more preferable compared to a large value of weight tuning. Lastly for the rate weight tuning, the response observe for the decrement of rate tuning shows a smaller error for a small value of rate weight. Hence, the rate weight tuning should be as small as possible in order for the MPC controller to reach its desired value. All of the responses for MPC must be refined more in order to take into account the performance of the valve as a fast response for a controller can damage the valve.

In conclusion, based on the study and simulation that had been done, the best controller for PID on distillation column is IMC based tuning and for MPC controller it is better to use a lower value of Np as long as it obeys the rule that Np must be more than the value of Nc. Hence, a small value of Np, Nc, weight tuning and rate weight tuning must be tuned for MPC controller to obtain the best result.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In conclusion the design and tuning of a distillation column controller is a complicated process which requires a lot of study.

This paper addresses a problem of determining the best parameter for PID controller and MPC controller which is going to provide the best result for a MIMO system; for example a distillation column control using wood and berry distillation column. This is because the distillation column is a very common type of equipment in the industry and it is quite a complicated process to determine the best tuning method in order to control both the composition of the bottom and top product.

Therefore, a thorough research on the controller settings and the tuning of the controller requires a lot of time. The methods that were selected will be able to determine the best controller setting for the distillation column. Hence, the project with the title of “Design and Tuning of a Distillation Column Control” is recommended to proceed due to its importance in chemical plants all around the world.

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