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PROCESS DYNAMIC AND CONTROL MODIFIED II QUADRUPLE TANK ON LABVIEW APPLICATION

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ABSTRACT

In general, industrial processes have a multi-variable characteristic, which is sensitive to the disturbances. Therefore, it is important to study the influences of disturbance through a simple but reliable tools. Quadruple tank is a simple tool in process control that represents a complex multivariable dynamic process. This article investigates the effects of an introduction of heaters to the system as well as the interaction among the tanks. The flow rates and energy inputs to the tanks, respectively, are considered as the manipulated variables, while the liquid temperatures and level are controlled; hence the system becomes a 4x4-MIMO. The closed loop simulation is designed for comparing controlled variable response between P only-PID and IMC conroller. Error criteria is evaluated by IAE. In level change of minimum phase, IAE's value of level and temperature controller IMC show better result than P-only. On the contrary, P-only controller indicated faster response (settling time) than IMC. IMC is used for solving time delay problem on conventional controller. Thus, based on settling time and wide range of tolerance, P-only shows a better work than IMC. However, using IMC is the best decision if the accuracy and precision from set point are the main of controlling system. In temperature change, based on settling time and IAE, IMC gives the best result than both P-only for level controlling and PID for temperature controlling. Divergent oscillation of controlled variable response, wether level or temperature, of non-minimum phase indicates unstable trend and hard to control by P-only for level and PID for temperature. In contrary, temperature change controlled variable result of IMC, either lavel control or temperature control, are indicated better result than P-only and PID. As a result, IMC controller can be considered to be a reference at non-minimum phase control system.

Keywords: IMC, P-only, PID, multivariable, controller.

INTRODUCTION

Chemical industry process is a series of processes that process raw materials into finished goods that have a higher economic value. In the application, the necessary process equipment often requires automatic control system. It is necessary to maintain the stability of the process in order to obtain optimal results. In general, the process is characterized as multivariable processes, and are affected by disturbance that can be detrimental to the process. Another common characteristic is the interaction between process variables and the time delay in the process.

Quadruple tank design is well known as Multi Input Multi Output (MIMO) system suitable for the analysis of the various control schemes that are non-linear. Some systems can not be represented by a linear model so that the non-linear model is needed. Nonlinear model in quadruple tank is caused by the square root relationship between flow and level in the tank. MIMO systems have interactions that is caused by some input variables that affect the use of more than one control variable [2]. This system uses four tanks with interaction in which there are two variables manipulation (input flow rate) and two measurable variables level of liquid tanks 1 and 2).

The 4-tank system is a simple but reliable equipment, which is able to represent a complex interaction [3].

The tanks are interconnected resulting in a very strong interaction between the liquid levels. However this system does not have a measure of time delay. Therefore, To represent the more complex such as introducing time delay, it is required to modify. A modification is made in the existing system by introducing heating in Tank 1 and Tank 2, respectively. The stream flow rate to Tank 1 and Tank 2, respectively, as well as the heat duty of Tank 1 and Tank 2, respectively, become the controlled variables.
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METHODS

Using a mathematical model and setting a specification of modification II quadruple tank system

Equipment scheme of modification II quadruple tank system can be seen at Figure-1.

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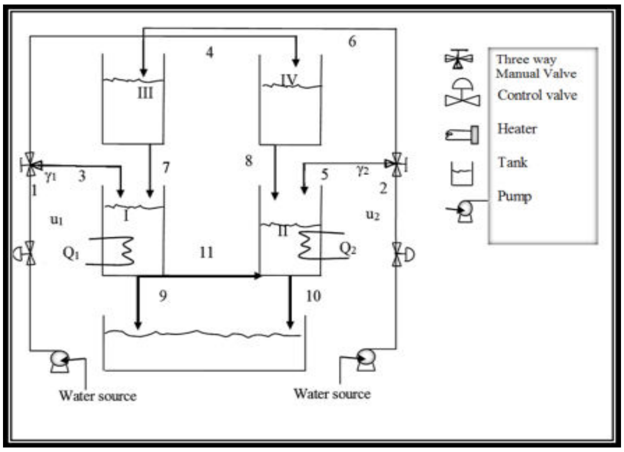

Figure-1. Equipment scheme of modification II quadruple tank system.

The equations used in the quadruple tank is non-linear equations derived from mass balance and Bernoulli equation for each tank :

$$A_i \frac{dh_i}{dt} = -a_i\sqrt{2gh_i} + q_{in} \quad (1)$$

The size of the tank diameter, height and diameter tank outlet are set. Then, after determining the flow rate ratio (γ1 and γ2), the water level in the tank, and the water temperature that is desired, it will get the magnitude of the flow rate of the pump and heater is given based on mass balance and energy balance in steady state condition.

Simulation of modification II quadruple tank system

Simulation steps in the general process are as follows: Stringing block diagram of the process model in the Control and Simulation Loop on the block diagram window, Designing a window display on the front panel to support the simulation process and analysis, and Running the system process that have been made and analyze the results obtained.

Identification of transfer function using step test method

The identification is made during open-loop system, which makes a step change by 3-5%. Curves are identified by means of the process according to the character approaches to the new process [7]. Schematic block diagram of 4x4 MIMO system is shown in the Figure-2.

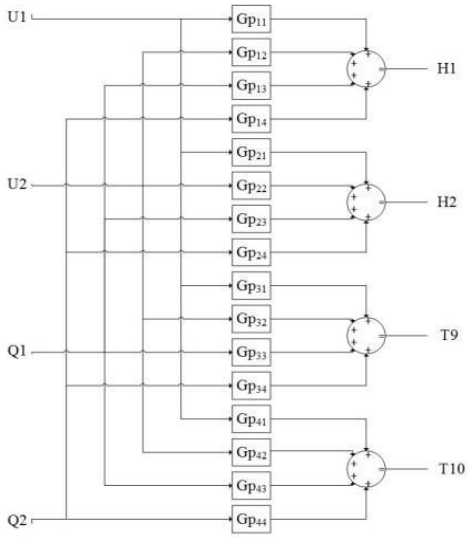

Figure-2. Block diagram scheme of 4x4 MIMO system.

Interaction analysis using relative gain array (RGA) method

The transfer function has been obtained from test step, then interaction is measured with the RGA method based on data from steady state gain. The result is the possibility of pairing configuration that is proposed for 4x4 MIMO system [5].

Set the parameter P-only - PID

Level controller is using P-only and temperature controller using PID. Parameters for each controller is calculated using the Ziegler-Nichols method and detuning Mc Avoy [6].

Closed loop simulation of MIMO P only – PID

Controller parameters which have been determined, is then used in a closed loop simulation. Simulation of MIMO P only - PID is carried out in LabView software by giving the changes in set point [1].

Set the transfer function and parameter of IMC controller

The transfer function of IMC controller is determined by the step test method. Tuning parameters τ_c by Rivera with $\tau_c > 0{,}8 * \theta$ and $\tau_c > 0{,}1 * \tau$ [7].

MIMO IMC simulation

Controller parameters which have been determined, then used in a closed loop simulation. Simulation of MIMO IMC is carried out in LabView software by giving the changes in set point.

Comparing response of MIMO P only- PID controller with MIMO IMC controller

Simulation results for MIMO P only - PID are compared with MIMO IMC. Closed loop response graphs are compared based on criteria IAE (integral of the absolute value of error).

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RESULTS AND DISCUSSIONS

Steady state simulation

This study aimed to carry out a simulation of the modified II quadruple tank system, then analyze the dynamics of the process and to compare responses between the closed loop process P only-PID controller and IMC controller. To perform the simulation stage, the determined specifications and process parameters as shown in the Table-1 and Table-2:

Table-1. Models specification of modified II quadruple tank.

Magnitude	Value
$h_1=h_2=h_3=h_4$	50 cm
$D_1=D_2=D_3=D_4$	20 cm
$A_1=A_2=A_3=A_4$	314,3 cm^2
$d_1=d_2=d_3=d_4$	0,925 cm
$d_1'=d_2'$	0,683 cm
$a_1=a_2=a_3=a_4$	0,6723 cm^2
$a_1'=a_2'$	0,3665 cm^2

Table-2. Process parameters.

Magnitude	Value
ρ	1000 kg/m^3
g	9,8 m/s^2
C	4220 J/kg K
T_{ref}	0 °C
$T_{fresh\ water}$	303 K
$k_1=k_2$	1

The scheme of modified II Quadruple Tank as shown in the Figure-3.

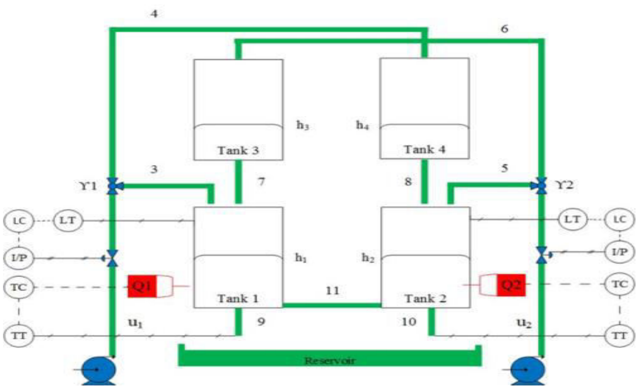

Figure-3. Scheme of modified II quadruple tank system on labview.

After determining the specifications and process parameters, then created simulated modified II quadruple tank system with a scheme like in the picture above. Four-tank system interact with each other, wherein the flow rate (U1) is divided into two streams are streams 3 and 4 with ratios γ1. Nor has the flow rate (U2) is divided into streams 5 and 6 with a ratio γ2. 4 streams fill the tank 4 and 6 flow filling the tank 3. In the second modification systems, horizontal interaction between the tank 1 and 2 through a side stream number 11 but with a surface area smaller pipe (a ') than the surface area of the bottom of the tank output pipe (a), except that the modification is done every additional heating supplied (Q1 and Q2). In the process control system, the controlled variables are the level of water in tank 1 and 2 (H1 & H2) as well as the temperature of the tank output 1 and 2 (T9 and T10). While the manipulated variables are flow rate (U1 & U2) and heat supplied (Q1 and Q2). So that the system becomes multivariable 4x4. The desired steady state conditions in the simulation process using Labview software listed in the Table-3:

Table-3. Steady state condition.

Magnitude	Value (Minimum phase)	Value (Non Minimum phase)
$\gamma_1=\gamma_2$	0,7	0,4
$\overline{H_1}$	0,253 m	0,253 m
$\overline{H_2}$	0,250 m	0,250 m
$\overline{H_3}$	0,016 m	0,156 m
$\overline{H_4}$	0,030 m	0,042
$\overline{T_9}$	40 °C	40 °C
$\overline{T_{10}}$	40 °C	40 °C
$\overline{U_1}$	0,1726 L/s	0,1026 L/s
$\overline{U_2}$	0,1259 L/s	0,1959 L/s
$\overline{Q_1}$	6707,91 J/s	6709,54 J/s
$\overline{Q_2}$	5887,55 J/s	5885,84 J/s

Transfer function identification

Transfer function identification is giving step 5% in the open-loop system after reaching a steady state. Graph response obtained FOPDT identified. U1 changes affect all control variables, variables H1 increased due to the addition of the flow to the tank 1, the addition of the flow to the tank 1 that increases the flow from one tank into the tank 2 so that an increase in the level of the tank 2, on the other hand, the addition of water with the temperature lower into the tank 1 resulting temperature in the tank 1 and tank 2 decreases. Vice versa with an increased flow of U2. Then the change does not affect the variable Q1 H1 and H2 are shown with a constant response both before and after the addition of a step change step, barring problems assuming the desired temperature does not exceed the boiling point of water, but the rise in influence variables T10 Q1 because a stream runs from the tank 1 into the tank 2. While Q2 changes only affect the control variable T10. Thus the transfer function matrix obtained in accordance with previous studies [4]:

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$$\begin{bmatrix} H_1(s) \\ H_2(s) \\ T_9(s) \\ T_{10}(s) \end{bmatrix} = \begin{bmatrix} Gp_{11} & Gp_{12} & 0 & 0 \\ Gp_{21} & Gp_{22} & 0 & 0 \\ Gp_{31} & Gp_{32} & Gp_{33} & 0 \\ Gp_{41} & Gp_{42} & Gp_{43} & Gp_{44} \end{bmatrix} \begin{bmatrix} U_1(s) \\ U_2(s) \\ Q_1(s) \\ Q_2(s) \end{bmatrix}$$

Interaction analysis

The preparation of the block diagram for a 4x4 MIMO system relies on the pairing controller used. From the calculation of the relative gain value (RGA), obtained:

Minimum phase (γ_1=0,7; γ_2=0,7)

Recommendations are choosing the pairing based on the relative value of the gain to a positive value and as close as possible to 1.

$$\Lambda = \begin{bmatrix} 7{,}1546 & -6{,}1546 & 0 & 0 \\ -6{,}1546 & 7{,}1546 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So the pairing is chosen, namely:

H1-U1 H2-U2
T9-Q1 T10-Q2

At the moment in the minimum phase ($\gamma1$ = 0.7; $\gamma2$ = 0.7), the magnitude of the flow rate into the tank 1 and 2 are greater than the magnitude of the flow rate into the tank 3 and 4. These conditions resulted in the water level in the tank 1 more easily controlled by the flow rate of the pump 1 and the water level in the tank 2 are more easily controlled by the flow rate of the pump 2. So as to control the level of use pairing H1-U1 and H2-U2.

Steady state conditions for the tank level 1 is 0.253 m and 0.25 m 2 tank. The circumstances resulting in the flow of water in the connecting pipes running from the tank 1 to tank 2. The water temperature in the tank 1 is strongly influenced heater 1 and the temperature of the water in the tank 2 is strongly influenced heater 2. Thus temperature controllers used for pairing T_9-Q_1 and T_{10}-Q_2.

Non minimum phase (γ_1=0,4; γ_2=0,4)

Recommendations are choosing the pairing based on the relative value of the gain to a positive value and as close as possible to 1.

$$\Lambda = \begin{bmatrix} -13{,}193 & 14{,}1930 & 0 & 0 \\ 14{,}1930 & -13{,}193 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So the pairing is chosen, namely:

H1-U2 H2-U1
T9-Q1 T10-Q2

At the moment in non-minimum phase ($\gamma1$ = 0.4; $\gamma2$ = 0.4), the magnitude of the flow rate into the tank 3 and 4 is greater than the magnitude of the flow rate into the tank 1 and 2. These conditions resulted in the water level in the tank 1 more easily controlled by the flow rate output tank 3 and the water level in the tank 2 is more easily controlled by the flow rate output tank 4 because the tank 3 and 4 have more water volume. So as to control the level of use pairing H1-U2 and H2 -U1. Similarly, the process at the minimum phase, pairing controllers used are T9-Q1 and T10-Q2.

Response control analysis

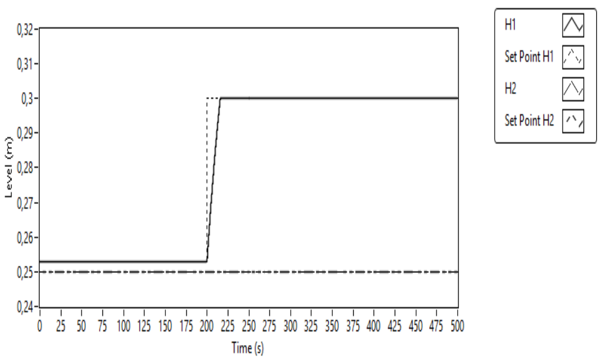
Minimum phase (γ_1=0,7; γ_2=0,7)
P *only* – PID controller

P-only controller - PID parameter are calculated using the Ziegler-Nichols method and the method of Mc Avoy detuning parameter obtained on each controller as shown at Table-4.

Table-4. Detuning results parameter P only-PID controller by Mc Avoy.

Pairing Controller	P-only	PID		
	Kc	Kc	τI	τD
H1 - U1	1,47	51,92		
H2 - U2	1,47	52,00		
T9 - Q1		8,08	3,90	0,97
T10 - Q2		15,41	1,95	0,49

The above parameters are used for closed-loop simulation, then change set point at each control variables and generate a response as in the Figure-4 and 5.



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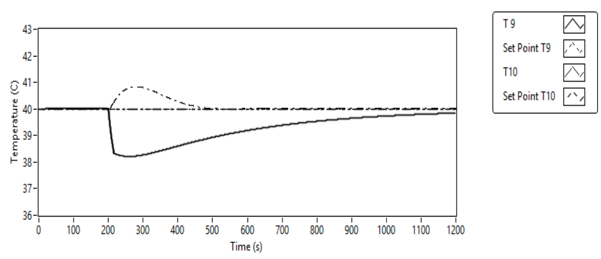

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Figure-4. (a) Level, (b) Temperature minimum phase simulation results using P-only controller – PID against change set point H1.

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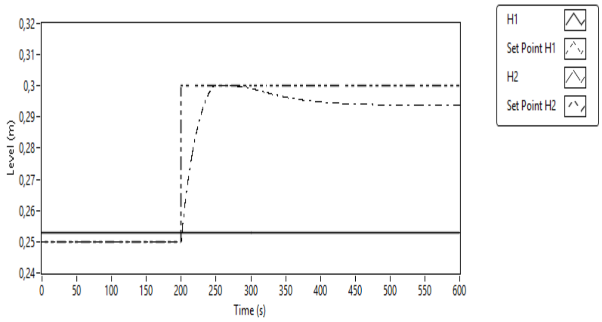

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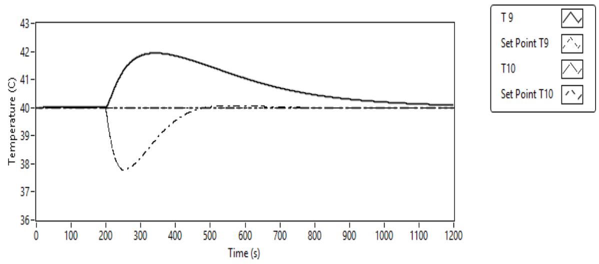

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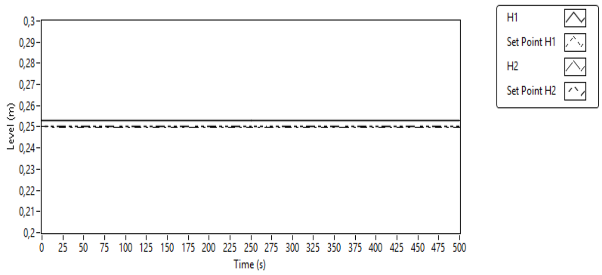
Figure-5. (a) Level, (b) Temperature minimum phase simulation results using p-only controller – PID against change set point H2.

Closed loop simulations performed on systems with minimum phase, in the process given the change set point level (H1) from 0.253 to 0.3 at 200 seconds. Based on simulation results, the response process may reach set point without any offset within 20 seconds. Similarly, when do change the set point H2 of 0.25 to 0.3. Results showed response process reaches the set point within 40 seconds, but then stabilized at 0.294 that show offset 0.006. The slight offset can be overcome by setting parameters using other methods, so that the response process in accordance with the desired set point. From these results it can be said that the P controller only enough to overcome the level of modified II quadruple tank.

The change of set point at the level resulted in the slight disturbance in the temperature control. From the graph it can be observed that the simulation results when set points in H1 was changed, there was a slight decline of T9 due to increasing number of incoming fresh water. While in the tank 2 (T10) there was a slight rise in temperature as a result of the increase in the flow of hot water from the tank 1 to tank 2. This also occurs when set points in H2 was changed. Based on the analysis, temperatures change in the two tanks can be resolved either by PID controller, it can be seen from T9 and T10 temperature back to set point without any offset. The time required to achieve the set point which is 700 seconds. So it can be said that the temperature controller on the system is working well, but it takes a long time to reach set point.

The simulation results for the change set point at T9 and T10 can be seen in the Figure-6 and 7.



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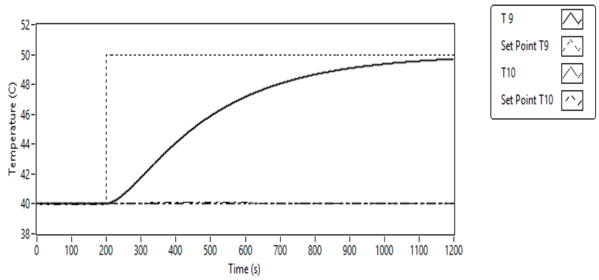

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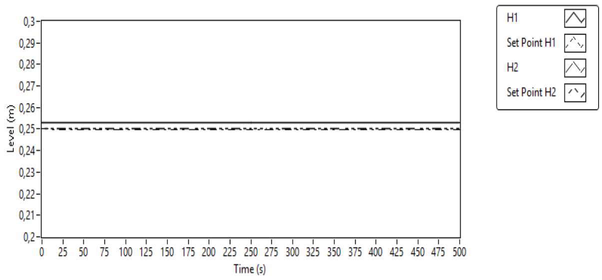
Figure-6. (a) Level, (b) Temperature minimum phase simulation results using P-only controller – PID against change set point T9.



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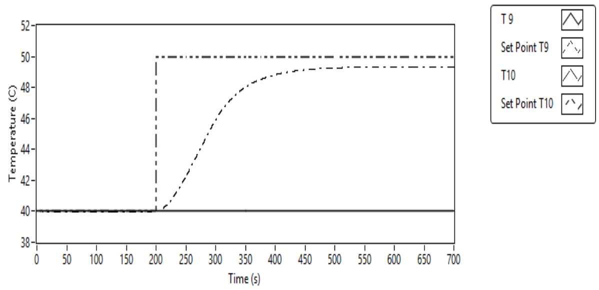

(b)

Figure-7. (a) Level, (b) Temperature minimum phase simulation results using P-only controller – pid against change set point T10.

Closed loop simulations performed on systems with minimum phase, in the process given the change temperature (T9) set point of 40 to 50 at 200 seconds. Based on simulation results, the response process may reach set point without any offset within 900 seconds (15 minutes). Similarly, when do change the set point T10

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from 40 to 50. Results showed response process can achieve the set point in a faster time, 300 seconds (5 minutes). There is little difference where the controlling T9 takes longer than T10 controllers to achieve the set point. This happens due to the calculation parameters are not right or the methods used are still not able to cope with this control system.

A temperature set point (T9 and T10) change did not cause interference with the control level. There is no interaction between Q1 and Q2 with the H1 and H2. So when set point temperature changes, there is no change in level. Response process remains stable at set point early.

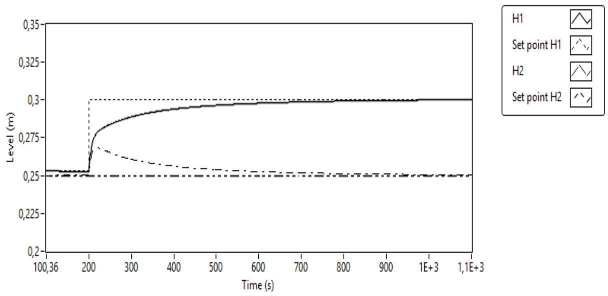
IMC controller

Ʈc parameter was calculated by Rivera method, to process containing time delay as the temperature control is used Ʈc / θ> 0.8 and for the process without time delay as the level control is used Ʈc> 0,1Ʈ, following a table IMC controller parameter tuning results:

Table-5. IMC controller parameter tuning.

Pairing Controller	IMC Ʈc
H1 - U1	11,70
H2 - U2	11,20
T9 - Q1	1,58
T10 - Q2	0,78

The above parameters are used for closed-loop simulation, then do change each variable set point control and produce a response as in the Figure-8 and 9.



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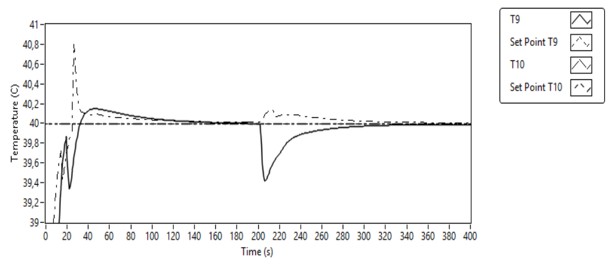

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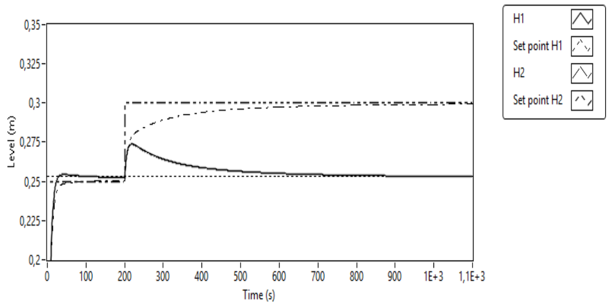
Figure-8. (a) Level, (b) Temperature minimum phase simulation results using IMC controller against change set point H1.



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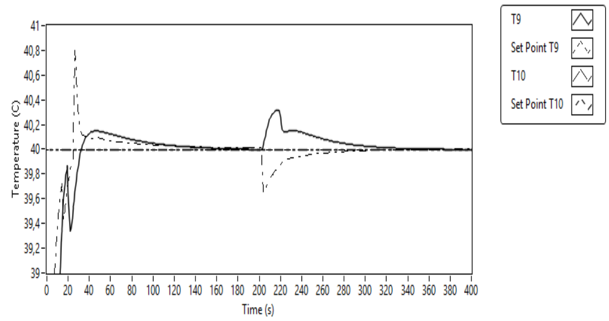

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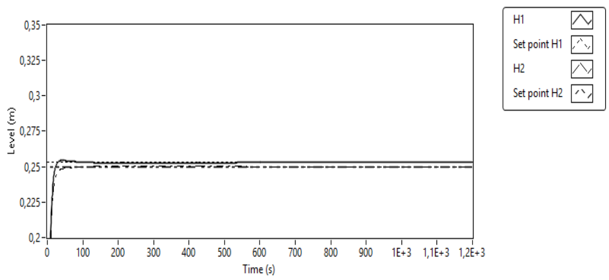
Figure-9. (a) Level, (b) Temperature minimum phase simulation results using IMC controller against change set point H2.

In the closed-loop simulations carried out changes in the set point level (H1) of 0.253 to 0.3 at 200 seconds. Based on simulation results, the response of the control variables H1 can reach set point without any offset within 450 seconds (7.5 minutes). Similarly, when do change the set point H2 of 0.25 to 0.3. The response of the control variables H2 can reach set point without any offset within 550 seconds (9 minutes). From these results it can be said that the IMC controller is good enough in controlling the level of modification II four-tank system, but requires quite a long time.

The level change of set point resulted slight disturbance in the temperature control. Temperature changes can be addressed properly by the IMC, it can be seen from T9 and T10 temperatures are returned to the set point without any offset in less than 50 seconds.

The simulation results for the change set point at T9 and T10 can be seen in the Figure-10 and 11.



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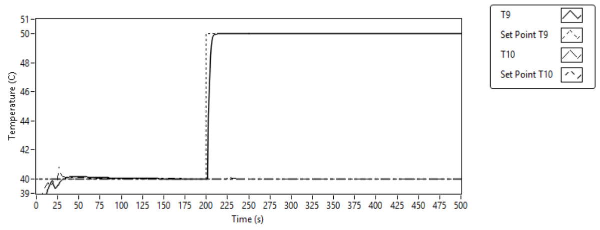

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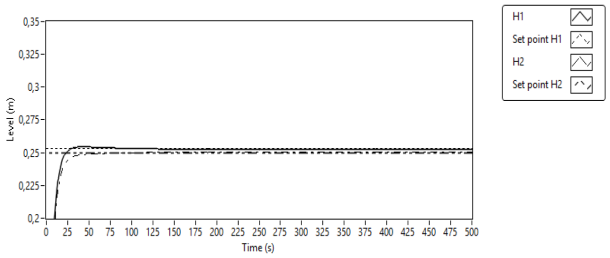
Figure-10. (a) Level, (b) Temperature minimum phase simulation results using IMC controller against change set point T9.



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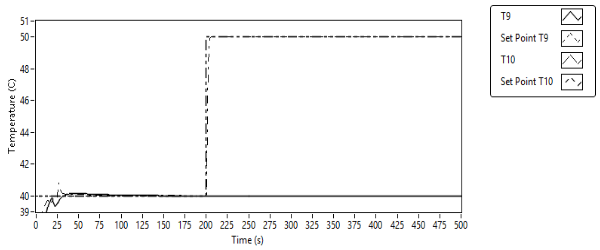

(b)

Figure-11. (a) Level, (b) Temperature minimum phase simulation results using IMC controller against change set point T10.

In the closed loop simulation given set point change T9 of 40 to 50 at 200 seconds. Based on simulation results, the response of control variables T9 can reach set point without any offset within 10 seconds. Similarly, when do change the set point T10 from 40 to 50. The response of the control variables T10 can achieve the set point faster is 5 seconds.

A change in the temperature set point (T9 and T10) do not cause interference with the control level. This is consistent with the results of the analysis of the dynamics process that has been discussed in the previous section. Response process remains stable at set point early. While changes T9 no significant impact on the T10.

There are several factors that show the superiority of the controller with other controllers, including the settling time, behavior charts before reaching set point that is oscillating or not, and the integral of the absolute value if error (IAE) which shows the integral of the difference between the set point with control variable response.

The value of IAE in closed loop Minimum phase response modified II quadruple contained in the Table 6:

Table-6. Closed loop response of P only-PID IAE's value.

Perubahan set point	IA							
	P-only		PI		IM			
	H	H	T	T1	H	H	T	T1
H	7,03	3,28	773,05	144,49	3,53	3,70	23,15	9,54
H	6,70	9,32	834,02	317,02	3,51	4,10	14,56	8,11
T	3,44	2,65	3149,59	48,03	0,16	0,15	43,82	3,50
T1	3,44	2,65	7,96	1529,1	0,16	0,15	6,57	20,14

At the level changes, the value of IAE in the control level by IMC is smaller than P-only controller, likewise occur at temperatures between IMC control with PID, but by the time required to reach set point, P-only faster than the IMC. IMC is used to overcome the problems posed by the process that has a time delay on conventional controllers so as to control the level in terms of settling time P-only more appropriately used to record the value of the set point accuracy tolerance is relatively large. However, if the precedence of control are more likely towards the achievement of set point accuracy than speed, the IMC is more appropriately used to control levels. As for temperature control, IMC is more appropriately used than PID.

At the change of temperature, controller IMC superior to the P-only in controlling the level and PID temperature control either seen by IAE value or settling time.

Non Minimum Phase (γ_1=0,4; γ_2=0,4)

P only-PID controller

Parameter obtained on each controller as shown at Table 7.

Table-7. PID controller parameter detuning result.

Pairing Controller	P - only	PID		
	Kc	Kc	τI	τD
H1 - U2	1,98			
H2 - U1	1,16			
T9 - Q1		14,96	1,95	0,49
T10 - Q2		115,77	0,25	0,06

The parameters are used for closed-loop simulation, then made changes to the set point on H1 and generates a response as in the Figure-12.

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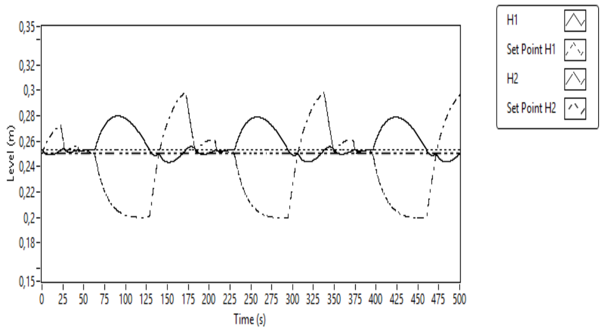
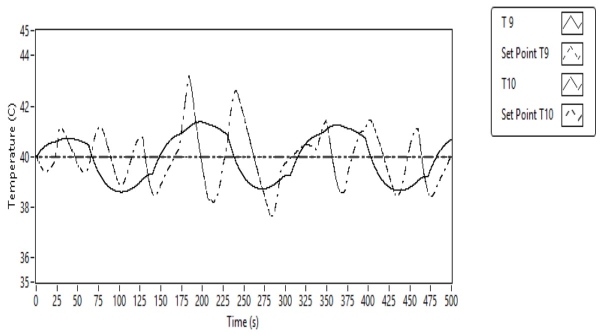


(a)



(b)

Figure-12. (a) Level, (b) Temperature non minimum phase simulation results using P-only controller –PID.

For non-minimum phase, process simulation cannot run properly. In the initial condition of the closed loop system, the process cannot reach set point, it can be observed in the graph above. Oscillation in response to the level and temperature of the process happened at the beginning of the circumstances set point value equal to the value of open-loop steady state process. Based on observations simulation, tank 3 filled with water, but the tank 4 is empty. While the tanks 1 and 2 are supposed to be controlled, but the system cannot be controlled properly.

Systems with non-minimum phase, the flow rate to the bottom of the tank by 40% and to the top of the tank by 60%. In this case the ratio of flow rate to the top tank is greater than the flow rate to the bottom tank, so that the system tends to be unstable. The water level in the tank 1 and 2 are controlled, but the rate of water flow more into the tank 3 and 4, so that the bottom of the tank level is more influenced by output stream from the top tank. Things like this are very difficult to control both level and temperature, because the level of the tank bottom is more affected than the output flow tank on stream manipulation of the pump flow rate. In the event of a change set point on the tank 1 and 2, then the tank 3 and 4 susceptible to overflow or not filled with water at all.

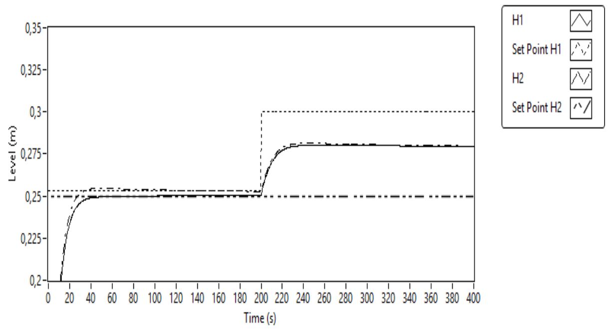
IMC controller

At IMC controller, do the same tuning with minimum phase. Table 8 shows the tuning τc result:

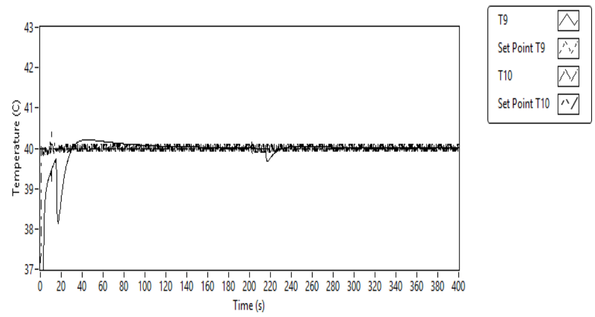
Table-8. IMC controller parameter tuning result.

Pairing Controller	IMC
	τc
H1 - U2	16,90
H2 - U1	13,80
T9 - Q1	0,79
T10 - Q2	0,1

The above parameters are used for closed-loop simulation, then do the changes set point at each control variables and generates a response as in the Figure-13 and 14:

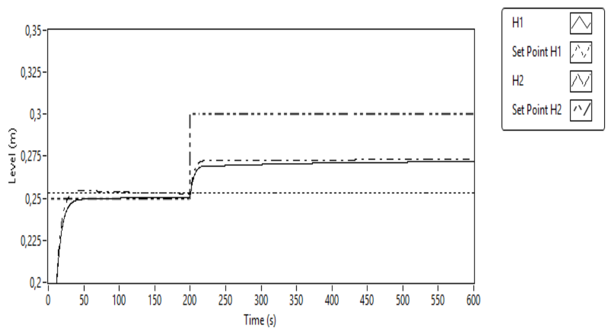


(a)



(b)

Figure-13. (a) Level, (b) Temperature non minimum phase simulation results using IMC controller to change set point H1.



(a)

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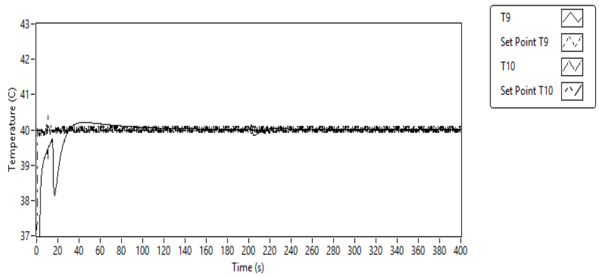
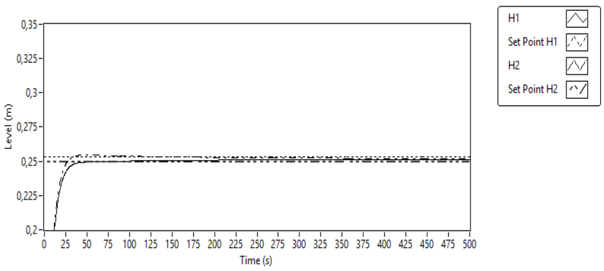


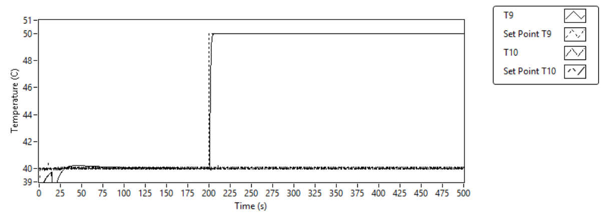
(b)

Figure-14. (a) Level, (b) Temperature non minimum phase simulation results using IMC controller to change set point H2.

In the closed-loop simulations carried out changes in the set point level (H1 and H2). In contrast to the level of the minimum phase is easy to control, on systems with non-minimum phase response tends to produce unstable after controlled. This can be seen from the response of the control variables H1 and H2 are offset 0.125 m from the set point. Small value of ɣ1 and ɣ2 resulted water flowing into the tank top (3 & 4) is greater than the flow of water to the bottom tank (1 & 2) and the level of the top tank (3 & 4) tend to be high so that flow out of the top tank towards the bottom tank tends to be greater when compared to the minimum phase, it can provide a significant interference effect of the steady system at the bottom tank (1 & 2). Thus, the control variables H1 and H2 are located on the tank system 1 and 2 will be more difficult to control on non-minimum phase compared with the minimum phase. As described in the previous section, change the set point at 18-20% level does not have a significant effect on the variable temperature control. Figure-15 and 16 show the results of the simulation to change the set point temperature.

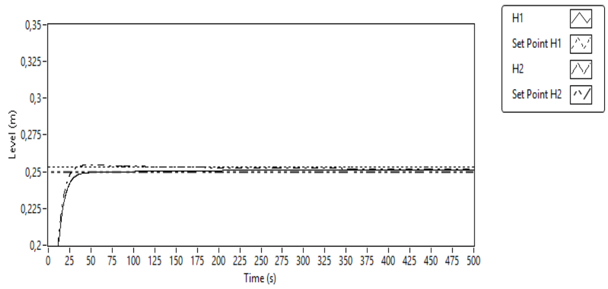


(a)

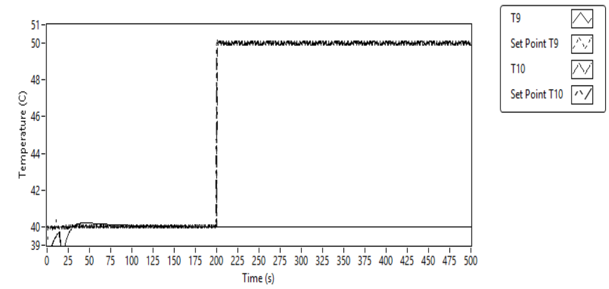


(b)

Figure-15. (a) Level, (b) Temperature non minimum phase simulation results using IMC controller to change set point T9.



(a)



(b)

Figure-16. (a) Level, (b) temperature non minimum phase simulation results using IMC controller to change set point T10.

In the closed loop simulation given T9 change the set point temperature of 40 to 50 at simulation time of 200 seconds. Based on simulation results, the response of the control variables T9 can reach set point without any offset within 5 seconds. Similarly, when do change the set point T10 from 40 to 50. The response of the control variables T10 can reach the set point in a faster time is 1 second. Too rapid response reach set point because the installation of the limit (constraint) heat flow (Q) is relatively difficult in block diagram form IMC transfer function. In contrast to the control level changes, the temperature control on the change in temperature gives good results. As discussed in the previous section, the IMC is used to overcome the problems posed by the process that has a time delay on conventional controllers so as to control process temperature containing time delay, IMC can work optimally.

Level control system is not good if there is one empty tank or overflow. Tank level non minimum phase control system categorized unstable, but when the controller cannot cope with this process it can be said that the controllers are used not right. In addition, methods of tuning and detuning method used is also greatly affect the performance of the controller. So that the Ziegler-Nichols method of tuning and detuning Mc Avoy method cannot produce a good level control system on non-minimum phase when compared with the same method on the minimum phase.

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CONCLUSIONS

Modified II quadruple tank system can be simulated using the Labview software. The simulation can be used to analyze the dynamics of the process and control system with a display that user friendly.

Based on the open-loop simulation and test step identification, transfer function contains a time delay and can be approached with FOPDT system.

In minimum phase, if the preferred of level control is the set point accuracy achievement than the speed, IMC is more appropriately used. Meanwhile, if the response speed of the control variables to achieve the set point is preferred, then the P-only more appropriately used. In the temperature control, IMC is more appropriately used than PID.

In non-minimum phase, the response variable level control tends to be unstable and difficult to control with P only and IMC. In the temperature control, IMC can be used as a reference control.

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