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ANALYSIS OF DIFFERENT CONTROLLERS FOR PILOT PLANT BINARY DISTILLATION COLUMN

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Abstract This article presents design and analysis of various PI controllers for a pilot plant binary distillation column. These PI controller has been tuned using Routh Hurwitz, Gain margin-Phase margin and Coefficient diagram methods. Due to the loop interaction and system with dead time designing a multi-loop controller is a challenging task. The diagonal elements in the overall open loop transfer function of the system, are reduced to first order model with dead time (FOPDT) model. This work aims on the comparative analysis based upon various performance measures such as integral of absolute error(IAE), integral of square error(ISE), integral of time square error (ITSE) and integral of time absolute error(ITAE) for a pilot plant binary distillation column.

Keywords: Coefficient diagram; decentralized controller; gain margin- phase margin; Routh Hurwitz.

1. INTRODUCTION

Most of the process industries are multiple input multiple output process. Design of controller for such processes is more complicated when compared with SISO processes, because of the interactions among the input-output variables. Therefore tuning of one loop cannot be carried out separately. Decentralized controllers are easy to implement, such design process consists of selections of control structure and design of SISO controller for each loop. In this current research, a simple decoupler plus a decentralized PI controller for tray temperature based on Routh Hurwitz stability criteria is presented for an interacting distillation column. In addition, expected closed loop performance of the processes is achieved through simulating the designed controller along with decoupler.

Distillation is frequently used segregation process in petrochemical industries. This process takes the difference in the boiling points to separate mixtures into two or more components. The vertical column consists of plates/trays, reboilerto provide necessary vaporization for the proces, reflux drum to collect the condensed vapor and condenser to cool the vapor leaving the top. Initially the feed F is introduces in the middle of the column, which divides the column into a rectifying section and stripping section. Heat is added to the bottom of the column as reboiler heat. In the present research, a mixture of Isopropyl alcohol and water in the ratio of 30% and 70% are considered for the distillation. The article considers the transfer function model for simulation. The reflux flow rate (L) is measured as LPH and reboiler power rate (Q) measured in KW are the manipulated variable (MV), whereas the temperature of tray 5 (T5) and tray 1 (T1) in deg.cel. are the controlled variable (PV). The research presents the simulation of control algorithm using MATLAB/Simulink software. All the four performance indices are analyzed for all the three different PI controller for closed loop servo response.

The remainder of this article is organized as follows: Section2 gives a summary on decoupler design method. Section 3 details the derivations of tuning relations. Section 4 represents the comparison and simulation of

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various PI controller for the lab scale interacting distillation process and the performance indices are tabulated, followed by conclusion in Section 5

2. DECOUPLER DESIGN

Decoupler design is one of the widely accepted technique to diminish the interactions in the control loop. These are utilized to decouple the interacting or coupled processes. Also, decoupler decomposes a MIMO process into independent single loop sub-systems. The Wang et al. method is utilized to design the decoupler for TITO processes. Let the TITO process is as follows

$$G_P(s) = \begin{bmatrix} g_{11}(s)e^{-\tau_{11}s} & g_{12}(s)e^{-\tau_{12}s} \\ g_{21}(s)e^{-\tau_{21}s} & g_{22}(s)e^{-\tau_{22}s} \end{bmatrix} \quad (1)$$

Let the off-diagonal elements of $G_P(s)$ have no RHP poles and diagonal elements of $G_P(s)$ have no RHP zeros then decoupler matrix is as

$$D(s) = \begin{bmatrix} \vartheta_1(s) & d_{12}(s)\vartheta_2(s) \\ d_{21}(s)\vartheta_1(s) & \vartheta_2(s) \end{bmatrix} \quad (2)$$

Where $\vartheta_1(s), \vartheta_2(s), d_{12}(s)$and $d_{21}(s)$ are determined from the following equation

$$\vartheta_1(s) = \begin{cases} 1 & \tau_{21} \geq \tau_{22} \\ e^{(\tau_{21}-\tau_{22})s} & \tau_{21} < \tau_{22} \end{cases} \quad (3)$$

$$\vartheta_2(s) = \begin{cases} 1 & \tau_{12} \geq \tau_{11} \\ e^{(\tau_{12}-\tau_{11})s} & \tau_{12} < \tau_{11} \end{cases} \quad (4)$$

$$d_{12}(s) = -\frac{g_{12}(s)}{g_{11}(s)} e^{-(\tau_{12}-\tau_{11})s} \quad (5)$$

$$d_{12}(s) = -\frac{g_{21}(s)}{g_{22}(s)} e^{-(\tau_{21}-\tau_{22})s} \quad (6)$$

3. CONTROLLER DESIGN METHOD

3.1. Routh Hurwitz Method

Consider a MIMO processes with time delay given as

$$\mathbf{G(s)} = \begin{bmatrix} \mathbf{g_{11}e^{-\theta_{11}s}} & \mathbf{g_{12}e^{-\theta_{12}s}} \\ \mathbf{g_{21}e^{-\theta_{21}s}} & \mathbf{g_{22}e^{-\theta_{22}s}} \end{bmatrix} \quad (7)$$

The overall open loop transfer function is

$$\mathbf{q_{11}(s)} = \frac{\mathbf{g_{11}g_{22}}}{\mathbf{g_{22}}} - \frac{\mathbf{g_{12}g_{21}}}{\mathbf{g_{22}}} \quad (8)$$

$$\mathbf{q_{22}(s)} = \frac{\mathbf{g_{11}g_{22}}}{\mathbf{g_{11}}} - \frac{\mathbf{g_{12}g_{21}}}{\mathbf{g_{11}}} \quad (9)$$

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These open loop transfer function obtained are approached into FOPDT model as

$$\mathbf{q_{ii}}(\mathbf{s}) = \frac{\mathbf{K_{ii}e^{-L_{ii}s}}}{\mathbf{T_{ii}s+1}} \qquad (10)$$

It is convenient to first approximate the dead time terms using Pade approximation given as

$$\mathbf{exp}(-\mathbf{L_{ii}s}) \approx \frac{\mathbf{1-\alpha s}}{\mathbf{1+\alpha s}} \qquad (11)$$

Where $\boldsymbol{\alpha} = \mathbf{0.5} * \mathbf{L_{ii}}$, considering the ideal form of PI controller

$$\mathbf{G_c}(\mathbf{s}) = \mathbf{K_c}\left(\mathbf{1} + \frac{\mathbf{1}}{\boldsymbol{\tau_I}\mathbf{s}}\right) \qquad (12)$$

Where K_c and $\boldsymbol{\tau_I}$ represents the gain and reset time of the controller. The characteristic equation of the closed loop is given as

$$\mathbf{1} + \mathbf{q_{ii}}(\mathbf{s})\mathbf{G_c}(\mathbf{s})=0 \qquad (13)$$

Using (10), (11) and (12), the characteristic equation becomes

$$\mathbf{1} + \left(\frac{\mathbf{K_{ii}}}{\mathbf{T_{ii}s+1}}\right) * \left(\frac{\mathbf{1-\alpha s}}{\mathbf{1+\alpha s}}\right) * \mathbf{K_c}\left(\mathbf{1} + \frac{\mathbf{1}}{\boldsymbol{\tau_I}\mathbf{s}}\right) = \mathbf{0} \qquad (14)$$

The simplified characteristic equation (8) becomes

$$\tau_I T_{ii}\alpha_{ii}s^3 + [T_{ii} + \alpha_{ii} - \alpha_{ii}K_cK_{ii})]\tau_I s^2 + [\tau_I + K_cK_{ii}\tau_I - K_cK_{ii}\alpha_{ii}]s + K_cK_{ii} = 0 \qquad (15)$$

Eq. 10 gives the condition for controller parameters such as integral time and gain of the controller.

$$\mathbf{0} < \mathbf{K_cK_{ii}} < \mathbf{T_{ii}}/\boldsymbol{\tau_D} \qquad \boldsymbol{\tau_I} > \boldsymbol{\alpha} \quad \boldsymbol{\tau_D} > \boldsymbol{\alpha} \qquad (16)$$

The necessary and sufficient condition of Routh-Hurwitz stability is given by

$$\tau_I > \max(\alpha, \tau_{I,\min A}) \qquad (17)$$

$$\boldsymbol{\tau_{I,\min A}} = \frac{\mathbf{K_cK_{ii}\alpha}}{\mathbf{1+K_cK_{ii}}}\left[\mathbf{1} + \frac{\mathbf{T_{ii}-K_cK_{ii}T_{ii}}}{\mathbf{\alpha+T_{ii}+K_cK_{ii}T_{ii}-K_cK_{ii}\alpha}}\right] \qquad (18)$$

The scaling parameters $\mathbf{r_p}$ and $\mathbf{r}_i$ are used to determine the tuning parameters for a PI controller.

$$K_c = \frac{r_p}{K_{ii}}\left(\frac{T_{ii}}{\tau_I}\right), 0 < r_p < 1 \qquad (19)$$

$$\boldsymbol{\tau_I} = \mathbf{r_i}\left(\frac{\mathbf{T_{ii}}}{\mathbf{L_{ii}}}\right) * [\mathbf{max}(\boldsymbol{\alpha}, \boldsymbol{\tau_{I,\min A}})], \quad \mathbf{r_i} > \mathbf{1} \qquad (20)$$

4. SIMULATION RESULTS

4.1. VA Model

Figure 1 shows the real time setup of lab scale interacting distillation column. The open loop test is performed on the column in order to determine the process model. The manipulated variable are reflux flow and reboiler, the top and the bottom tray temperature T5 and T1 are the two process variables.

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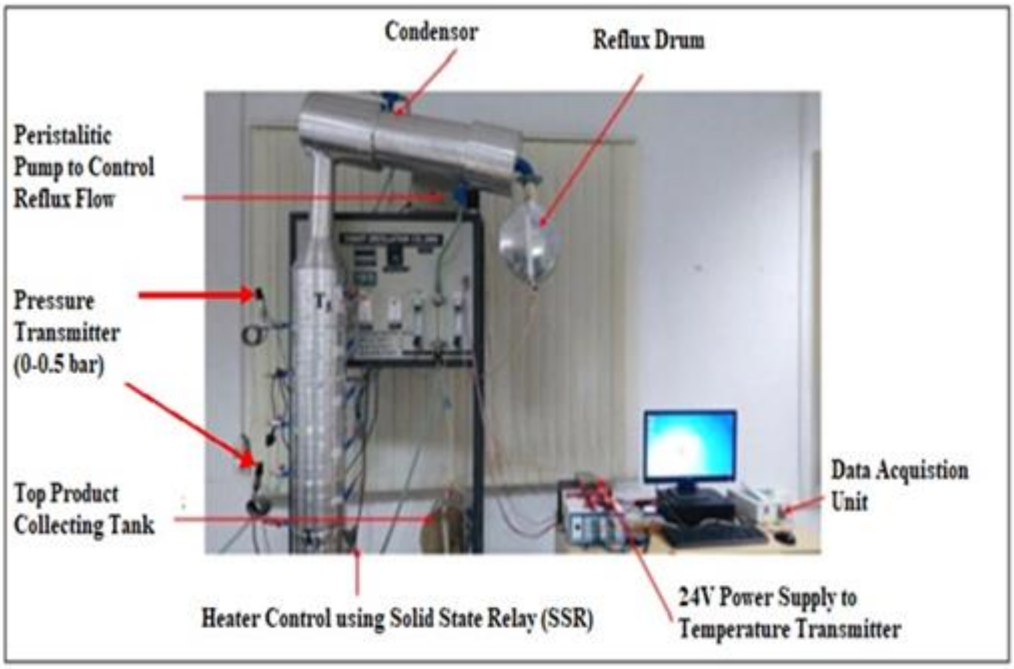

Figure 1. Lab scale interacting distillation column setup.

The FOPDT model of the pilot plant binary distillation column identified by Vinaya and Arasu is given by [3,4].

$$G(s)=\begin{bmatrix} \frac{-0.13e^{-0.03s}}{1.14s+1} & \frac{0.18e^{-0.03s}}{0.64s+1} \\ \frac{-0.34e^{-1.22s}}{1.23s+1} & \frac{0.18e^{-0.03s}}{0.32s+1} \end{bmatrix} \quad (21)$$

The model parameters like dead time and time constants are measured in hours hence the open loop data were converted into hours and the process gain is measured in °C/%. The open loop transfer function obtained in the form of FOPDT model as for Loop 1 and Loop 2 is

$$q_{11}=\frac{0.21e^{-2s}}{1.35s+1} \quad (22)$$

$$q_{22}=\frac{-0.29e^{-1.545s}}{0.735s+1} \quad (23)$$

Based on the necessary and sufficient condition of Routh Hurwitz stability consider the scaling parameters as for Loop 1 and Loop 2 as $\mathbf{r_p}=\mathbf{0.6}$ and $\mathbf{r}_i$=2 respectively. The PI Controller is obtained as

$$K_p=\begin{bmatrix} 1.9286 & 0 \\ 0 & -0.9843 \end{bmatrix} \quad K_I=\begin{bmatrix} 1.428 & 0 \\ 0 & -1.339 \end{bmatrix} \quad (24)$$

By substituting Eq. 14 and Eq.15 in Eq.8, the closed loop characteristic equation for VA model is obtained as

$$\mathbf{Loop\ 1: 1.8255s^3+2.625s^2+1.491s+0.405=0} \quad (25)$$

$$\mathbf{Loop\ 2: 0.417s^3+1.14s^2+0.735s+0.285=0} \quad (26)$$

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From Eq.19 and Eq.20 the coefficients of the characteristic equation obtained are positive. From the Routh array table shown in Table 1, it is obsereved that the elements in the first column are positive so that system is stable.

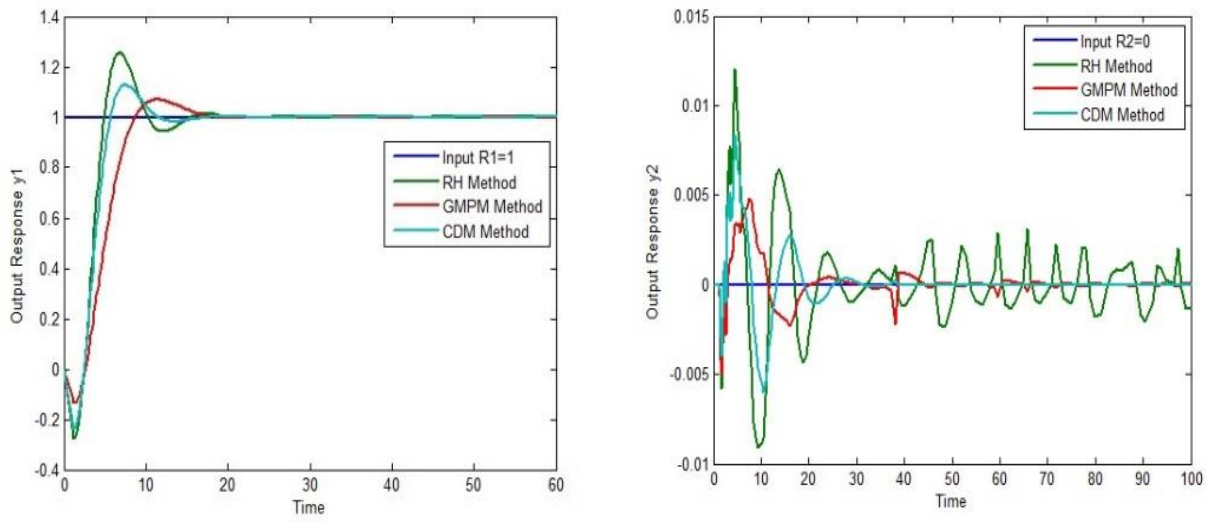
Table 1. Routh array.

Loop 1			Loop 2		
s^3:	1.8225	1.491	s^3:	0.417	0.735
s^2:	2.625	0.405	s^2:	1.14	0.285
s^1:	1.2098		s^1:	0.63075	
s^0:	0.405		s^0:	0.285	

Figure 2 and Figure 3 shows the closed loop servo response for the transfer function model of the process for the various PI controllers. Table 2 shows the tuning parameters values.

Table 2. PI Tuning parameters for various controller method.

Process Model	Controller Method	Controller Values	
		Kp	Ki
VA Model	Routh-Hurwitz Method	$\begin{bmatrix}1.9286 & 0\\ 0 & -0.9843\end{bmatrix}$	$\begin{bmatrix}1.428 & 0\\ 0 & -1.339\end{bmatrix}$
	Gain Margin-Phase Margin Method [6]	$\begin{bmatrix}0.8415 & 0\\ 0 & -0.4295\end{bmatrix}$	$\begin{bmatrix}0.9538 & 0\\ 0 & -0.8026\end{bmatrix}$
	Coefficient Diagram Method [5]	$\begin{bmatrix}1.706 & 0\\ 0 & -0.3374\end{bmatrix}$	$\begin{bmatrix}1.244 & 0\\ 0 & -1.068\end{bmatrix}$



(a) **(b)**

Figure 2. Servo response of Y1 and Y2 when input R1=1 and R2=0.

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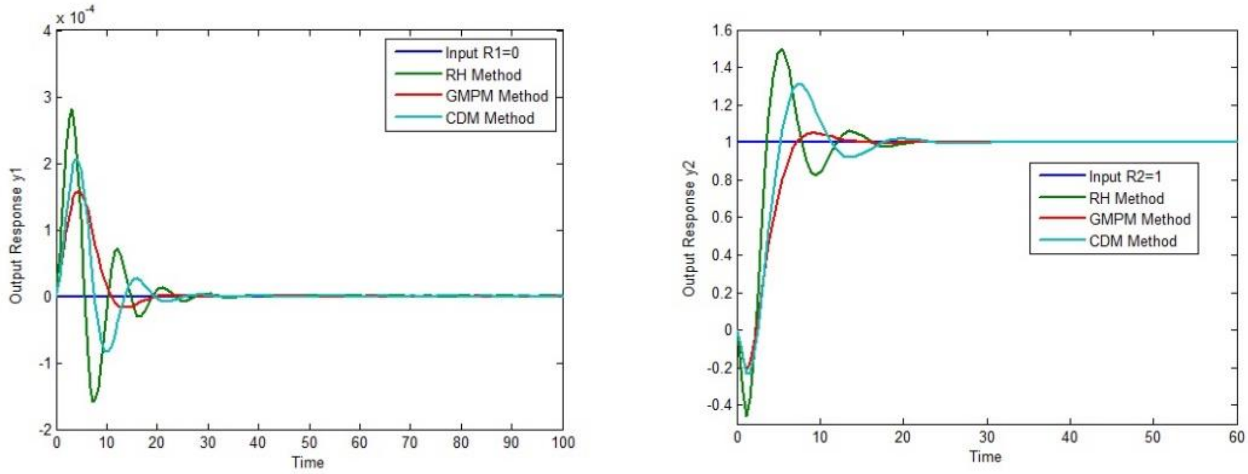

(a) **(b)**

Figure 3. Servo response of Y1 and Y2 when input R1=0 and R2=1.

Table 3. Comparison of performance index for servo response.

Method	**IAE**	**ISE**	**ITAE**	**ISTE**
Routh Hurwitz	10.16	8.39	27.69	16.32
Gain Margin-Phase Margin	10.45	8.79	32.28	17.79
Coefficient Diagram	10.42	8.58	36.25	16.53

5. CONCLUSION

In this article the simulation studies has been carried out for the identified model using decentralized control algorithm based on Routh Hurwitz, Gain margin-Phase margin and Coefficient Diagram. It is observed that controller gives good closed loop time domain response. This has been validated by comparison analysis of the performance indices for the various types of controller and is tabulated in Table 3.

FUTURE WORK

The above mentioned decentralized PI control methods can be extended for higher order stable process with time delay and also for unstable systems.

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References

[1] Mohd N., and Nandong J., 2018, Routh Hurwitz tuning method for a stable/unstable time delay MIMO processes, *IOP Conference series, Materials Science and Engineeirng.*

[2] Seer Q.H., and Nandong J., 2017, Stabilization and PID tuning algorithms for second order unstable processes with time delays, *ISA Transactions*, Vol.67, pp. 233-245.

[3] Vinayambika S. B., Thirunavukkarasu I., and Shanmuga P. S., 2016, An Experimental Study on Implementation of Centralized PI Control Techniques on Pilot Plant Binary Distillation Column, *International Journal of Chem. Tech Research*, Vol. 9, Iss. 11, pp. 244-251.

[4] Vinayambika S. B., Thirunavukkarasu I., and Shanmuga P. S., 2016, Design and Implementation of Decentralized PI controller for Pilot Plant Binary Distillation Column, *International Journal of Chem Tech Research*, Vol. 9, Iss. 12, pp. 284-294.

[5] Janani R. I., Thirunavukkarasu I., and Vinayambika S. B., 2018, Experimental Implementation of CDM based two mode controller for an Interacting 2*2 Distillation Process, *International Journal of Pure and Applied Mathematics*, Vol. 118, Iss. 18, pp. 2241-2251.

[6] Thirunavukkarasu I, Janani R., Yadav E.S, and Selvanathan S.P., Modeling and Control of tray temperature along with column pressure in a pilot plant distillation column, *International conference on Automation, Computational and Technology management 2019*, pp. 450-454.