https://doi.org/10.24191/jeesr.v26i1.011

Reformulated Tangent Method Application in PID Tuning for Controllability of Agarwood Hydro Distillation Pot

Nurul Nadia Mohammad, Muhamad Shahir Ashraf Zulkifli, Mohd Hezri Fazalul Rahiman, and Najidah Hambali *

***Abstract*— This study evaluates the effectiveness of transfer function-based control strategies for the Agarwood hydro distillation process. To stimulate the nonlinearity of the system dynamics, pseudo random binary signal (PRBS) and multi-sine (M-Sine) signals were used as perturbation input signals. Using data gathered from the distillation pot, the System Identification tool in Matlab was used to determine the transfer function. The easiest open-loop test that has been executed on a real plant is the Reformulated Tangent Method (RTM). The Proportional-Integral-Derivative (PID) tuning rules developed by Ziegler Nichols (ZN), Cohen Coon (CC), and Takahashi (Taka) were employed in this work. Analysis of the relative performances of PID-ZN, PID-CC, and PID-Taka was done based on transient reactions including settling time, rising time, and percentage of overshoot. To adjust better result, the value of PID gains was changed using the fine-tuning method. The results of the investigation showed that, in comparison to other tuning rules, the CC tuning strategy generated superior results for PRBS input in terms of faster rising time and settling time as well as a smaller percentage of overshoot.**

***Index Terms*—Distillation, Fine-Tuning, Reformulated Tangent Method, PID Tuning, Temperature**

I. Introduction

Distillation is now one of the methods commonly used in industrial processes to extract essential oils [1, 2]. Distillation columns are frequently used in industrial processes, such as chemical processes, since they display nonlinear dynamic behaviour and offer a nonlinear behaviour when operated at high purity levels [3, 4]. The extensive use of Proportional-Integral-Derivative (PID)'s can be partially attributed to their versatility and ease of use [5, 6]. The controller can really be tuned rather easy, unlike many contemporary controllers that are significantly more sophisticated. PID Ziegler-Nichols technique is the most repeatedly employed methods for selecting the controller settings based on a plant's transient step response [7], [8].

According to earlier studies, applying linear modelling to a nonlinear system leads to subpar accuracy and fit performance [9], [10]. Furthermore, the linear model had a number of drawbacks owing to the rationality of a limited input series in contrast to the nonlinear model, which provided broader capacity, a more accurate representation of the nonlinearity behavior of the process in a nonlinear system, and improved performance [3], [9], [11]. In addition, distillation column control techniques have several issues or limits, such as complexity in process control example that involves temperature-dependent reactions and phase changes (e.g., liquid to vapor), which are inherently nonlinear. Furthermore, in some cases, in a distillation pot, a sudden dip in power supply could nonlinearly reduce the heating rate therefore, the linear model might underestimate the recovery time, causing delays in regaining optimal operation and thus leading to overshoots [12] and performance that is less effective [13]. A few number of studies that aimed on the perturbation input signal in controlling the distillation column have also been exposed [3], [11]. Only a few numbers of research have looked into thorough accurate transfer function estimation of the nonlinear system with PID control in distillation columns [14]–[16].

To show the nonlinearity of the system dynamics, system identification requires a large enough perturbation input signal. Which system region will be simulated should be sufficiently clear from the input and output data utilized for system identification [17]. The pseudo random binary signal (PRBS) perturbation input signal, which is recognized for its capacity to excite the process over a wider range of frequencies and amplitudes, is sufficient, according to a number of studies [18]. Utilizing multi-sine (M-Sine) input data is the next stage since it offers additional details for matching a parametric model and improves the detection of the proposed adaptative response. Since M-Sine is sensible, it can identify even minute changes that take place during testing [19].

For a variety of industrial processes, PID control is crucial. Most elements of the industrial process can be controlled by it. The PID controller performed better for temperature control than the P and PI controllers because it increases system precision [16, 20]. The tuning law's controller parameters, such as those from the Cohen Coon (CC), Chein-Hrones-Reswick (CHR), Ziegler-Nichols (ZN), and Takahashi tuning procedures, were used to get the optimum rate for proportional, integral, and derivative gains [21]. The Takahashi, ZN, and CC tuning methods were utilized in this study, and the performance

This manuscript is submitted on August 5, 2024, revised on January 13, 2025, and accepted on February 18, 2025. Nurul Nadia Mohammad is from School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, Cawangan Johor, Kampus Pasir Gudang, Johor, Malaysia.
Muhamad Shahir Ashraf Zulkifli, Mohd Hezri Fazalul Rahiman and Najidah Hambali are from College of Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.

*Corresponding author
Email address: najidah@uitm.edu.my

of the controls will be assessed to see which tuning method is best. Reformulated Tangent Method (RTM) is a straightforward approach that may be used to gather parameter data and calculate the PID value for closed-loop testing [22].

The goal of this study is to investigate the influences of various tuning strategies on the process response in order to analyze the controllability of an agarwood hydro distillation pot using two perturbation input signals. In this work, the hydro distillation pot process is made dynamic using the reformulated tangent technique recommended by [23]. The performance of the closed-loop system is assessed using dynamical performance indicators for example percent overshoot (%OS), settling time (Ts), and rising time (Tr). The study also addresses limitations in earlier works that relied on linear modeling for nonlinear systems, which often led to inaccuracies. By adopting nonlinear system identification techniques and advanced PID tuning, the paper demonstrates how to overcome these challenges effectively. Overall, the RTM offers a systematic and efficient approach to PID tuning, aimed at optimizing the controllability and stability of complex processes. In this study, the method is applied to the hydro distillation process of agarwood, a technique widely used for extracting essential oils. Agarwood distillation is highly sensitive to temperature and other dynamic parameters, making precise control essential to ensure quality and efficiency. By leveraging the reformulated tangent method, this research seeks to fine-tune the PID controller parameters to enhance the stability and responsiveness of the distillation pot, ensuring optimal extraction performance and process reliability. Also, the application of the reformulated tangent method provides a novel and systematic approach to PID tuning, overcoming limitations of traditional tuning methods and offering broader applicability to dynamic and sensitive processes.

The hydro distillation procedure used to extract agarwood is demonstrated in Section II. Section III goes into further depth on the methodology utilised to obtain the results. The performance of the controls is discussed in further depth in Section IV, Results and Discussions. Section V includes the analysis of the results.

II. EXPERIMENTAL SETUP

The hydro distillation process used to extract agarwood is shown in Fig. 1. The system includes a tank made of stainless steel, a hot plate for heating, a copper condenser, and an RTD for sensing. With the use of 240 Vac power supply, STOM 1 controls the power that powers the heater. An open-loop experiment was conducted with a sampling time of 1 second using a 3V input step signal. The voltage range of 3V is used because this voltage optimal for exciting the system without damaging the equipment and it align with typical operating conditions.

The agarwood and water solution that had been poured into the tank's bottom served as the starting point for the procedure. The material and the tank will both receive heat from the hot plate, which will eventually form the hot vapour that will lead them out through the condenser. The created hydrosol will be collected in the container for collection. Using input signals from PRBS and MSINE, the time-varying water temperature dataset is displayed in Fig. 2 and Fig. 3 respectively.

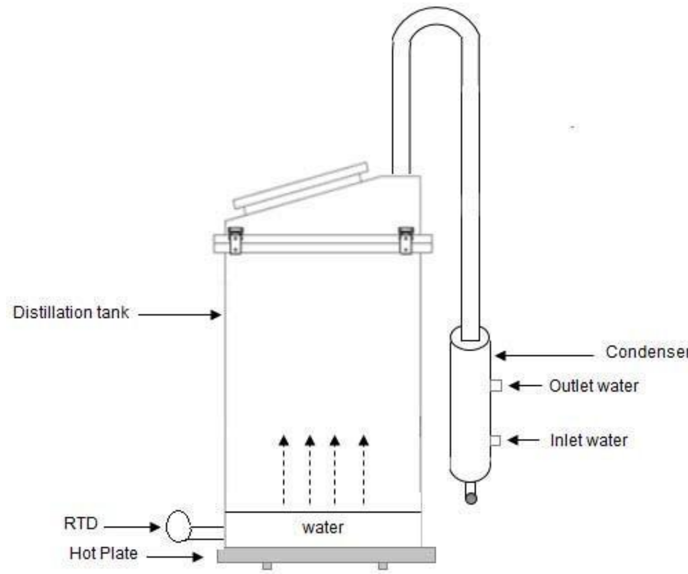

Fig. 1. Hydro distillation process

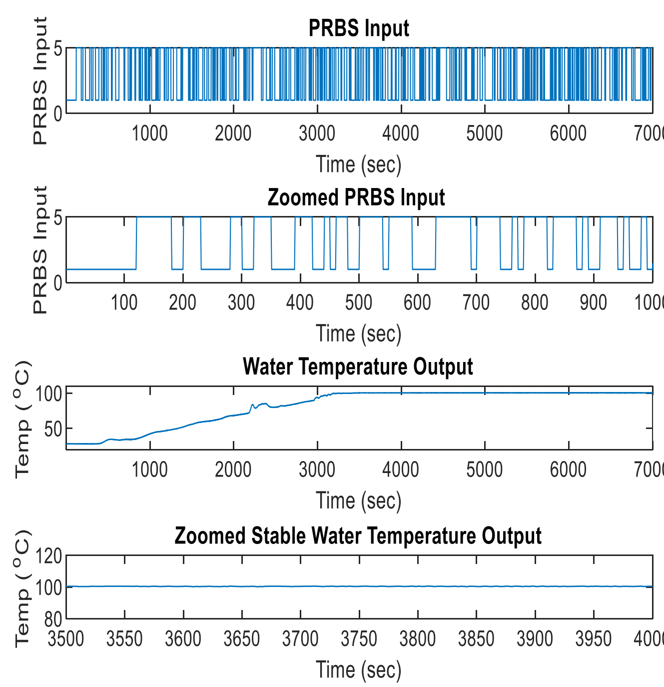

Fig. 2. Water Temperature dataset for PRBS input

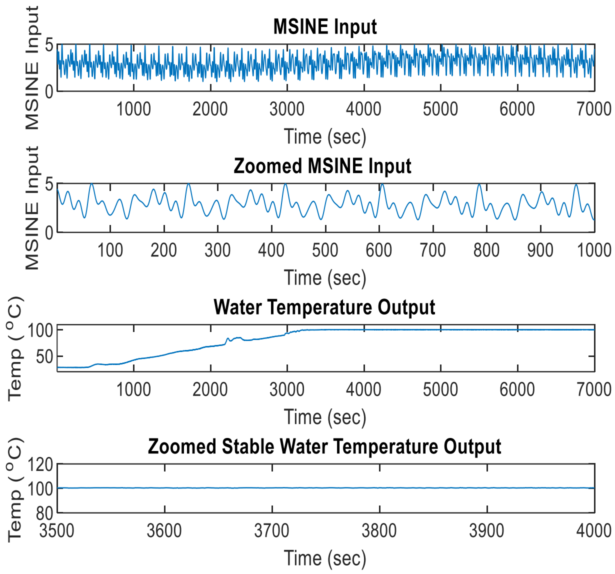

Fig. 3. Water Temperature Dataset for MSINE

III. Methodology

Accurate estimation of transfer functions is critical for designing effective control strategies, and the formulated tangent method offers a precise approach for identifying system parameters, even in complex and nonlinear systems. Once a reliable transfer function is established, PID control will be approached into the system and its simplicity, effectiveness, and ease of implementation can be applied to adjust system outputs and correct performance errors using proportional, integral, and derivative actions.

A. Transfer Function Estimation

The transfer function was calculated from the time domain input using the MATLAB System Identification tool. To estimate the transfer function, the number of poles and zeros was set during system identification. The best transfer functions were chosen based on the greatest model output fit and a lower number of final prediction errors (FPE) and mean-square errors (MSE). The PID controller will then be built for both perturbation signals using the best predicted transfer function. Final prediction error (FPE), as seen in (1);

$$FP = det\left(\frac{1}{N}\sum_{1}^{N} e(t,\hat{\theta}_N)\left(e(t,\hat{\theta}_N)\right)^T\right)\left(\frac{1+\frac{d}{N}}{1-\frac{d}{N}}\right) \quad (1)$$

where
N = number of values in the estimation data set,
$e(t)$ = vector of prediction errors,
θ_N = estimated parameters,
d = number of estimated parameters.

Using historical data and the MSE equation, the One Step Ahead (OSA) prediction model's capability for future value prediction is determined as follows:

$$MSE = \frac{\sum_{i=1}^{n}(e_i)^2}{n} = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n} \quad (2)$$

Low MSE values obtained from the residual magnitude indicate a good model fit. To determine how accurately the transfer function model fits data, the R-Squared method is utilized. This is how the R-Squared is calculated:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2} \quad (3)$$

Where yi and $\hat{yi}$ are, respectively, real and estimated observations at the interval, i. The number of observations is n, and the mean of the y variable is $\overline{yi}$. To achieve the best results, MSE should have a low value and R2 should have a high value [10]. Strong agreement is indicated by an MSE of less than 5.0, while a perfect match is indicated by an MSE of less than 1.0 [23]. All models that have been examined are regarded to have strong R-Squared coefficients of determination if they are larger than 0.75, with higher values suggesting better agreement [24]. The most appropriate data may be shown once the model selection criteria have been constructed, as explained.

B. Reformulated Tangent Method

The reformulated tangent [22, 24, 25] is a method for assessing an open-loop test result. It is seen in Fig. 4. By drawing a tangent line to the response curve's sharpest point, this technique analyses the response curve. The reaction rate (RR), the interval between the tangent line's intercept and the output change that caused it (Td), and the process time constant (Tc) are all calculated using this response curve.

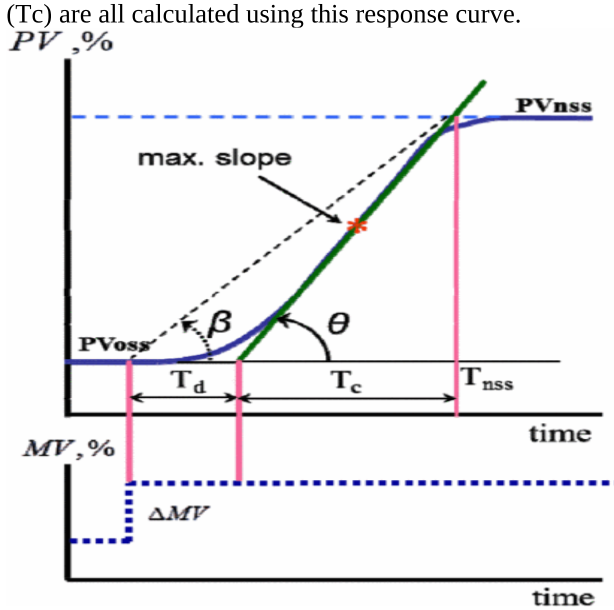

Fig. 4. Transforming process rate into trigonometric form

Response rate, RR:

$$RR = \frac{tan\theta}{\Delta MV}\frac{a}{b} \tag{4}$$

Dead time, T_d:

$$T_d = b\left(\frac{time}{length}\right) \times length \tag{5}$$

where;

RR reaction rate, l/time
ΔMV change in controller's output, %
a scaling factor for y-axis, %/length
b scaling factor for x-axis, time/length

The time when process variable (PV) achieves new steady state condition is given as:

$$T_{nss} = T_c + T_d \tag{6}$$

where;

T_c : Time constant, the time taken for the response to rise to 63.2% of its final value, sec

T_d : Dead time, time between the intercept of tangent line and the initiated change in output, sec

While the uncontrollability parameter:

$$\mu = \frac{T_d}{T_c} \tag{7}$$

C. PID Control and Tunings

From equation (8), where u is the control signal, e is error, Kp is proportional gain, Ti is integral time, and Td is derivative time, represents the optimal PID algorithm.

$$\mu(t) = K_P\left(e(t) + \frac{1}{T_i}\int_0^t e(t) + T_d\frac{de(t)}{dt}\right) \tag{8}$$

When a gain has to be tuned, PID tuning rules are recognised as the controller parameters that modified the process in each mode, including proportional, integral, and derivative. Unfortunately, the performance of the controller depends on one of its settings being set properly. Therefore, it is essential to follow the right procedure for fine-tuning the controller settings in order to have a high-quality control system.. The fine-tuning process involves making deliberate adjustments to these parameters. Increasing the PB that makes proportional gain lower can prevent the system from being overly sensitive to small errors and thus helping to avoid excessive oscillations or instability. Meanwhile increasing the D term improves the system's ability to respond to sudden changes in the process, enhancing stability and reducing oscillations. Table I provides a description of the tuning procedure formula used for this experiment.

TABLE I. PID TUNING PARAMETER

TUNING METHOD	PB (%)	I, sec	D, sec
ZN	$83.3RRT_d$	$2T_d$	$0.5T_d$
CC	$\frac{100}{1.35\left(1+\frac{\mu}{3}\right)}RRT_d$	$2.5T_d\left(\frac{1+\frac{\mu}{5}}{1+\frac{3\mu}{5}}\right)$	$\frac{0.37T_d}{1+\frac{\mu}{5}}$
Takahashi	$77T_dRR$	$2.2T_d$	$0.45T_d$

IV. RESULT AND DISCUSSION

In this section, estimation transfer function and reformulated tangent method has been indicated and performance of PID control tuning also been demonstrated.

A. Transfer Function Estimation

For the PRBS input and M-SINE input, respectively, the number of poles and zeros was modified to get the ideal transfer function model. Based on performance validation criteria, the findings in tables II and III indicate that the PRBS input with three numbers of poles and two numbers of zeros and the M-SINE input with three numbers of poles and three numbers of zeros exhibit the best performance.

TABLE II. TRANSFER FUNCTION ESTIMATION FOR PRBS INPUT

No. of zeros	No. of poles	R^2 (%)	MSE	FPE
0	1	80.9	24.18	24.2
	3	47.12	184.8	185.2
1	1	80.93	24.11	24.13
	3	69.8	60.4	60.54
2*	2	56.84	123.5	123.8
	3*	**92.37***	**3.861***	**3.871***
3	3	92.12	4.113	4.125
	5	52.59	149	149.6
4	4	92.7	3.473	3.486
	5	91.12	5.229	5.252

***The best result**

TABLE III. TRANSFER FUNCTION ESTIMATION FOR M-SINE INPUT

No. of zeros	No. of poles	R^2 (%)	MSE	FPE
0	1	67.23	71.19	71.25
	3	93.23	3.037	3.041
1	1	88.85	8.247	8.261
	3	45.36	198	198.4
2	2	87.71	10.01	10.03
	3	92.02	4.22	4.231
3	**3***	**92.07***	**4.171***	**4.183***
	5	90.39	6.127	6.148
4	4	48.91	173.1	173.7
	5	91.48	4.412	4.431

***The best result**

TABLE IV. VALUE OBTAINED OF PID TUNING PARAMETER

TUNING METHOD	PB (%)	I, sec	D, sec
ZN	224.5768	800	200
CC	190.4479	1003.789	143.807
Takahashi	207.592	880	180

Then, the transfer function for both input signals is obtained from the best performance validation criteria as shown in equations (9) and (10).

$$G(s)_{prbs} = \frac{0.0204s^2 + 1.257e^{-5}s + 7.088e^{-8}}{s^3 + 0.00231s^2 + 4.355e^{-6}s + 1.955e^{-9}} \quad (9)$$

$$G(s)_{msine} = \frac{0.1878s^3 + 0.10024 + 3.6s + 2.648e^{-7}}{s^3 + 0.009622s^2 + 8.022e^{-6}s + 8.6e^{-9}} \quad (10)$$

B. Reformulated Tangent Method

The RTM method ensures that the PID gains are accurately calculated, leading to optimal system response for the distillation process. This is crucial for handling the dynamic nature of temperature and pressure in a hydro distillation pot in order to achieve better stability and control over critical parameters like temperature. Furthermore, with precise tuning reduces energy consumption, minimizes overshoot or oscillations, and shortens the time to reach the desired steady state, improving the overall efficiency of the agarwood distillation process. By RTM method, the study aims to achieve a robust, efficient, and scalable control strategy tailored to the unique demands of hydro distillation. Equation 11-13 demonstrates the parameters of RTM tuning method.

Reaction rate, RR:

$$RR = \frac{tan45^{\circ}}{5-1}\frac{10^{\circ}/13\,mm}{1000\,s/35\,mm} = 0.00674/s \quad (11)$$

Dead time, T_d

$$T_d = 14mm \times \frac{1000s}{35mm} = 400s \quad (12)$$

Uncontrollability parameter from equation (7)

$$\mu = \frac{T_d}{T_c} = \frac{400}{2742.72} = 0.1458 \quad (13)$$

C. PID Control Performance

The results of the experiments conducted in real time for various tuning criteria are shown in this section. The outcomes will depend on how effectively the controller performs during real-time deployment. ZN, CC, and Takahashi are used to adjust the PID controller. The PID value for the closed-loop tuning approach is displayed in Table IV.

The desired temperature for this experiment was chosen at 85°C to evaluate the controllers' performance since that temperature is excellent for the oil to maintain its quality [26], [27]. The output performance is shown in Fig. 5 and Fig. 6 along with Table V tabulating the PID performance criteria.

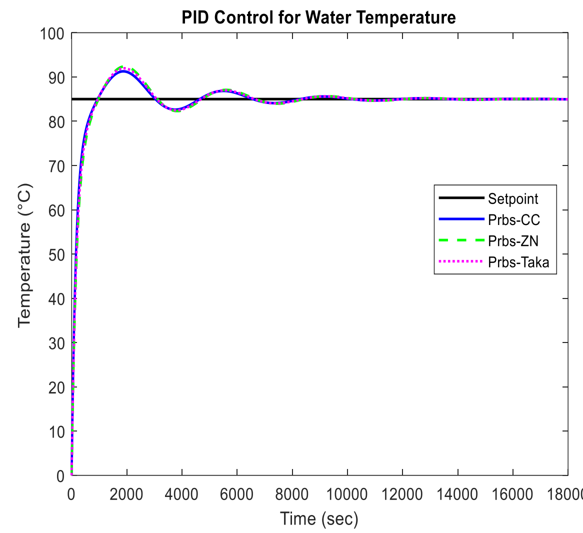

Fig. 5. PID control using PRBS input

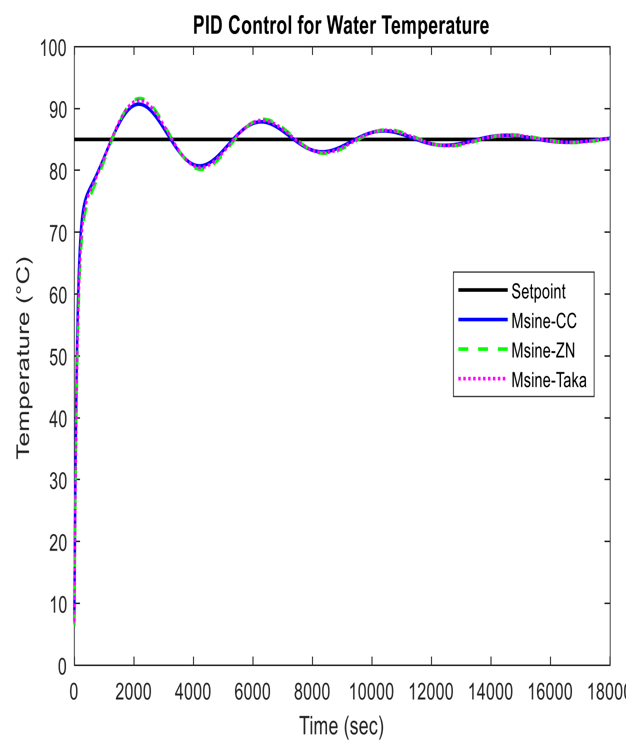

Fig. 6. PID control using Msine input

TABLE V. PERFORMANCES EVALUATION OF PID TUNING FOR PRBS AND M-SINE INPUTS

Input	Tuning Rule	Rise Time (s)	Settling Time (s)	%Overshoot
PRBS	ZN	525.8501	5.9870×10^3	8.7166
	CC	453.7398	5.7774×10^3	7.4349
	Takahashi	494.1441	5.9008×10^3	8.2400
M-Sine	ZN	624.9968	8.9615×10^3	7.8661
	CC	524.8714	8.7841×10^3	6.7517
	Takahashi	568.6852	8.8820×10^3	7.4400

According to Table V, rise time, settling time, and percentage overshoot are denoted as Tr, Ts, and OS %, respectively. The Cohen Coon tuning approach demonstrated the lowest percentage overshoot of 7.4349 % and 6.7517 % for PRBS input and M-SINE input, respectively, based on the closed-loop results. It also had the lowest rising time and settling time for both inputs.

D.Fine-Tuning

As indicated in Table VI below, fine-tuning [28] was used in this investigation to increase the amount of D by a fourth of the initial value of I while increasing the percentage of PB to double in order to get the best response in terms of Tr, Ts, and %OS. By fine-tuning PID controllers using the reformulated tangent method, the study minimizes energy consumption, reduces operational variability, and enhances the overall efficiency of the distillation process.

TABLE VI. OBTAINED VALUE OF PID AFTER FINE TUNNG

TUNING METHOD	PB (%)	I, sec	D, sec
ZN	449.1536	800	200
CC	380.8958	1003.789	250.95
Takahashi	415.184	880	220

The response curves of the PRBS input and the Msine input following fine tuning are shown in Figs. 7 and 8, respectively. As a consequence of the CC rule's fine-tuning, the percent overshoot result was better than that of ZN and Takahashi, which were 5.6414 % for PRBS input and 5.7268 % for Msine input. Table VII shows that CC also gave better results for PRBS input in terms of rising and settling times, which were $1.00x10^3s$ and $4.9454x10^3s$, respectively. The results showed that by creating a faster reaction and less overshoot, the CC controller has enhanced the responsiveness.

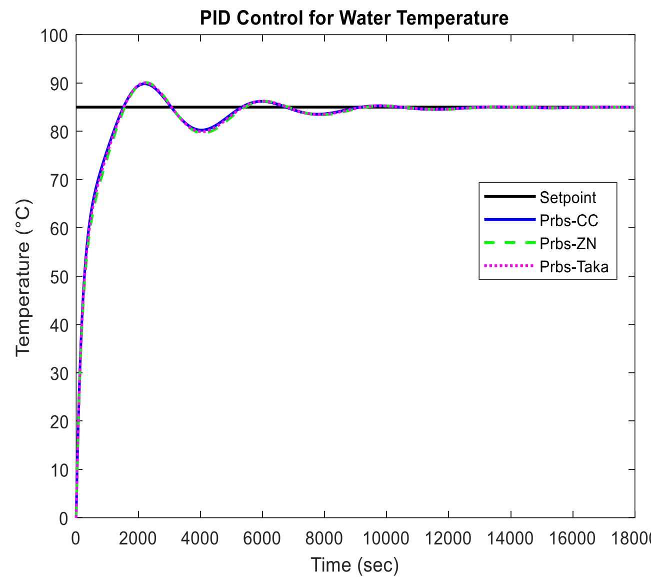

Fig. 7. PRBS input after fine

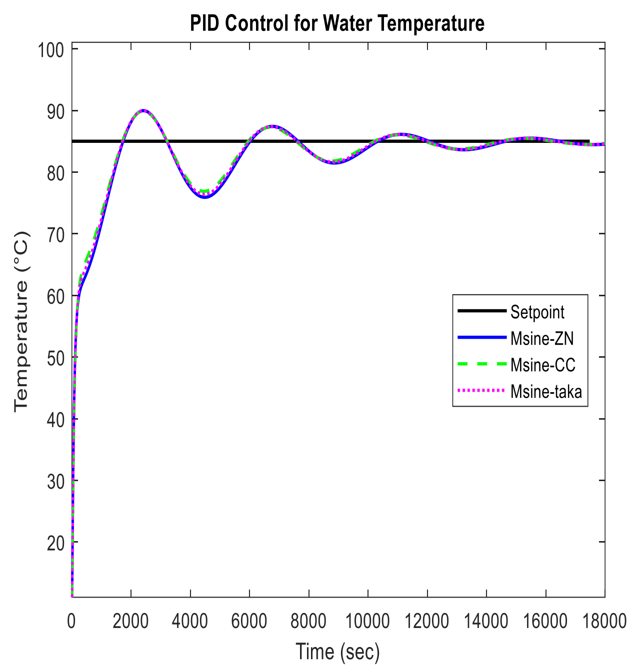

Fig. 8. MSINE input after fine tuning

TABLE VII. PID PERFORMANCE AFTER FINE TUNING

Input	Tuning Rule	Rise Time (s)	Settling Time (s)	Overshoot (%)
PRBS	ZN	1.0762×10^3	5.0681×10^3	5.9419
	CC	1.0000×10^3	4.9454×10^3	5.6414
	Takahashi	1.0374×10^3	4.9993×10^3	5.8924
M-Sine	ZN	1.2540×10^3	9.8071×10^3	5.8672
	CC	1.1932×10^3	9.6470×10^3	5.7268

Takahashi	1.2193x10^3	9.7088x10^3	5.8581

V. Conclusion

The PRBS input with three numbers of poles and two numbers of zeros and the M-Sine input with three numbers of poles and three numbers of zeros exhibit the best performance when compared to the other combinations, and the transfer function of the Agarwood Hydro Distillation Pot is estimated by using the MATLAB System Identification tool based on the best model output fit and a smaller number of final prediction error (FPE) and mean-square error (MSE).

In this study, the performance of the PID control was examined utilising the three tuning techniques ZN, CC, and Takahashi. Results revealed that PID control with CC tuning rules outperformed ZN and Takahashi tuning technique when using inputs that were both PRBS and M-Sine. The controller then underwent fine-tuning, which generated a good outcome by lowering system overshoot and producing a quicker reaction time than it did previously. It was demonstrated by the three control performance criteria, which included a quicker settling and rising time as well as a lower percentage of overshoot that was attained by the use of a CC tuning rule.

By using other input signals to encourage the nonlinearity of the system dynamics, such as Multi-level Pseudo Random Sequence (MPRS) and Random Gaussian Signal (RGS), this study may be broadened for future research. Additionally, Fuzzy-PID controllers can replace the conventional Proportional Integral Derivative (PID) method for nonlinear modelling and control in future study.

The results have practical implications for industries seeking optimized control strategies for similar nonlinear process. The structured approach to transfer function modeling and PID tuning provides a replicable framework for similar applications in industrial settings. This research pushes forward the understanding of control strategies in nonlinear systems like hydro distillation processes. It integrates theoretical and practical advancements, making it a valuable contribution to both academic research and industrial application.

Acknowledgment

The authors would like to thank to the College of Engineering, Universiti Teknologi MARA Shah Alam Selangor and Johor for support and facilities provided for this research.

References

[1] S. Syamsul, S. Suherman, and S. Y. Widianti, "IoT-Based Monitoring and Control on Essential Oil Distillation Systems," *Proceedings of the International Conference on Electrical Engineering and Informatics*, vol. 2022-October,pp.132–136,2022.

[2] L. Mehdi, AhlemAyoune, D. Bouchema, L. Ouassila, and M. Abdeslam-Hassen, "Optimization of extraction of essential oil from local Lavender (lavandula angustifolia) and evaluation of the antioxidant and antifungal activities," *2022 13th International Renewable Energy Congress (IREC)*, pp. 1–5, Dec. 2022, doi: 10.1109/IREC56325.2022.10002018.

[3] H. M. Shariff, M. H. Fazalul Rahiman, and M. Tajjudin, "Nonlinear system identification: Comparison between PRBS and Random Gaussian perturbation on steam distillation pilot plant," *Proceedings - 2013 IEEE 3rd International Conference on System Engineering and Technology, ICSET 2013*, pp. 269–274, 2013, doi: 10.1109/ICSENGT.2013.6650183.

[4] N. Hambali, M. N. Taib, A. I. M. Yassin, and M. H. F. Rahiman, "Nonlinear Modelling for Steam Temperature of Distillation Column: A Comparison between PRBS and MPRS Perturbation Signals," *Proceedings - 2018 IEEE Conference on Systems, Process and Control, ICSPC 2018*, pp. 78–83, Jul. 2018, doi: 10.1109/SPC.2018.8704132.

[5] M. Tajjudin, M. H. F. Rahiman, N. Ishak, R. Adnan, and H. Ismail, "Model evaluation of a steam distillation process for steam temperature regulation," *Proceedings - 3rd International Conference on Intelligent Systems Modelling and Simulation, ISMS 2012*, pp. 431–435, 2012, doi: 10.1109/ISMS.2012.130.

[6] C. B. Kadu and C. Y. Patil, "Design and Implementation of Stable PID Controller for Interacting Level Control System," *Procedia Comput Sci*, vol. 79, pp. 737–746, Jan. 2016, doi: 10.1016/J.PROCS.2016.03.097.

[7] N. Kamaruddin, Z. Janin, Z. Yusuf, and M. N. Taib, "PID controller tuning for glycerin bleaching process using well-known tuning formulas - A simulation study," *IECON Proceedings (Industrial Electronics Conference)*, pp. 1682–1686, 2009, doi: 10.1109/IECON.2009.5414748.

[8] K. H. Ang, G. Chong, and Y. Li, "PID control system analysis, design, and technology," *IEEE Transactions on Control Systems Technology*, vol. 13, no. 4, pp. 559–576, Jul. 2005, doi: 10.1109/TCST.2005.847331.

[9] M. D. M. Shah, N. N. Mohammad, and N. Hambali, "Nonlinear Modelling for Time-Varying Water Temperature PID Control," *Proceeding - 2021 IEEE 17th International Colloquium on Signal Processing and Its Applications, CSPA 2021*, pp. 177–182, Mar. 2021, doi: 10.1109/CSPA52141.2021.9377296.

[10] I. Rustam, I. Ismail, A. A. Ishak, and I. M. Yassin, "System identification of ethane-ethylene distillation process using linear and Nonlinear ARX approaches," *Proceedings - 2013 IEEE 4th Control and System Graduate Research Colloquium, ICSGRC 2013*, pp. 48–52, 2013, doi: 10.1109/ICSGRC.2013.6653274.

[11] H. M. Shariff, M. H. Marzaki, M. Tajjudin, and M. H. F. Rahiman, "System identification for steam distillation pilot plant: Comparison between linear and nonlinear models," *Proceedings - 2013 IEEE 3rd International Conference on System Engineering and Technology, ICSET 2013*, pp. 263–268, 2013, doi: 10.1109/ICSENGT.2013.6650182.

[12] R. Aruna and S. T. Jaya Christa, "Modeling, system identification and design of fuzzy PID controller for discharge dynamics of metal hydride hydrogen storage bed," *Int J Hydrogen Energy*, vol. 45, no. 7, pp. 4703–4719, Feb. 2020.

[13] Y. Wang, Q. Jin, and R. Zhang, "Improved fuzzy PID controller design using predictive functional control structure," *ISA Trans*, vol. 71, pp. 354–363, Nov. 2017, doi: 10.1016/J.ISATRA.2017.09.005.

[14} N. N. Mohammad *et al.*, "Performance comparison and energy consumption index between MPC and FuzzyPID in small-scaled agarwood distillation pot," *2018 9th IEEE Control and System Graduate Research Colloquium, ICSGRC 2018 - Proceeding*, pp. 156–161, Mar. 2019, doi: 10.1109/ICSGRC.2018.8657575.

[15] N. N. Mohammad, A. A. Azman, M. H. Marzaki, R. Adnan, M. H. F. Rahiman, and S. NizamTajuddin, "Evaluation on energy consumption in small-scaled agarwood distillation pot for PID controller," *Proceedings - 2017 IEEE Conference on Systems, Process and Control, ICSPC 2017*, vol. 2018-January, pp. 94–99, Jul. 2017, doi: 10.1109/SPC.2017.8313028.

[16] N. N. Mohammad, H. Norazman, and N. Hambali, "NARX Modelling and PID Controller in Monitoring Water Temperature of SDPP," *2022 IEEE 13th Control and System Graduate Research Colloquium, ICSGRC 2022 - Conference Proceedings*, pp. 120–125, 2022, doi: 10.1109/ICSGRC55096.2022.9845180.

[17] N. Hambali, M. H. F. Rahiman, M. N. Taib, and A. I. M. Yassin, "A review on nonlinear modeling for steam distillation system and its significance," *Proceeding - 2016 IEEE 12th International Colloquium on Signal Processing and its Applications, CSPA 2016*, pp. 328–333, Jul. 2016, doi: 10.1109/CSPA.2016.7515855.

[18] N. Hambali, M. H. A. Manan, and N. N. Mohammad, "Nonlinear Modelling and Fuzzy Control of Steam Temperature for Distillation Column Pilot Plant," *2022 IEEE 18th International Colloquium on Signal Processing and Applications, CSPA 2022 - Proceeding*, pp. 192–197, 2022, doi: 10.1109/CSPA55076.2022.9781931.

[19] T. E. Hudson and M. S. Landy, "Measuring adaptation with a sinusoidal perturbation function," *J Neurosci Methods*, vol. 208, no. 1, pp. 48–58, Jun. 2012, doi: 10.1016/J.JNEUMETH.2012.04.001.

[20] S. N. Ramli, N. N. Mohammad, and N. Hambali, "Modelling and Comparative Study of Ziegler Nichols and Takahashi PID Tuning for Time-Varying Water Temperature," *2021 IEEE 12th Control and System Graduate Research Colloquium, ICSGRC 2021 - Proceedings*, pp. 265–270, Aug. 2021, doi: 10.1109/ICSGRC53186.2021.9515224.

[21] N. Hambali, A. Masngut, A. A. Ishak, and Z. Janin, "Process controllability for flow control system using Ziegler-Nichols (ZN), Cohen-Coon (CC) and Chien-Hrones-Reswick (CHR) tuning methods," *2014 IEEE International Conference on Smart Instrumentation, Measurement and Applications, ICSIMA 2014*, Feb. 2015, doi: 10.1109/ICSIMA.2014.7047432.

[21] N. Hambali, Z. Janin, N. S. M. Samsudin, and A. A. Ishak, "Process controllability for air temperature oven system using open-loop Reformulated Tangent Method," *2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications, ICSIMA 2013*, 2013, doi: 10.1109/ICSIMA.2013.6717963.

[22] B. Nagaraj, S. Subha, and B. Rampriya, "Tuning Algorithms for PID Controller Using Soft Computing Techniques," *IJCSNS International Journal of Computer Science and Network Security*, vol. 8, no. 4, p. 278, 2008.

[24] A. A. Ishak and M. A. Hussain, "Reformulation of the tangent method for PID controller tuning," *IEEE Region 10 Annual International Conference, Proceedings/TENCON*, vol. 3, 2000, doi: 10.1109/TENCON.2000.892314.

[25] N. Hambali, M. N. K. Zaki, and A. A. Ishak, "Reformulated tangent method of various PID controller tuning for air pressure control," *Proceedings - 2012 IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2012*, pp. 17–22, 2012, doi: 10.1109/ICCSCE.2012.6487108.

[26] N. N. Mohammad, A. A. Azman, M. H. Marzaki, R. Adnan, M. H. F. Rahiman, and S. NizamTajuddin, "Evaluation on energy consumption in small-scaled agarwood distillation pot for PID controller," *Proceedings 2017 IEEE Conference on Systems, Process and Control, ICSPC 2017*, vol. 2018-January, pp. 94–99, Jul. 2017, doi: 10.1109/SPC.2017.8313028.

[27] S. N. H. Johari, M. H. F. Rahiman, R. Adnan, and M. Tajjudin, "Real-time IMC-PID Control and Monitoring of Essential Oil Extraction Process Using IoT," *2020 IEEE International Conference on Automatic Control and Intelligent Systems, I2CACIS 2020 - Proceedings*, pp. 51–56, Jun. 2020, doi: 10.1109/I2CACIS49202.2020.9140207.

[27] M. A. Majid, Z. Janin, and A. A. I. M. N. Taib, "Temperature control tuning for overdamped process response," *2009 5th International Colloquium on Signal Processing & Its Applications*, pp. 439–444, Mar. 2009, doi: 10.1109/CSPA.2009.5069267.

[28] A. R. Utami, R. J. Yuniar, A. Giyantara, and A. D. Saputra, "Cohen-Coon PID Tuning Method for Self-Balancing Robot," *ISESD 2022 - 2022 International Symposium on Electronics and Smart Devices, Proceeding*, 2022, doi: 10.1109/ISESD56103.2022.9980830.