American Journal of Chemical Engineering
2024, Vol. 12, No. 6, pp. 123-131
https://doi.org/10.11648/j.ajche.20241206.11

Research Article

Genetic Algorithm-Based PID Optimization for Ethyl Acetate Saponification in a Continuous Stirred Tank Reactor

Mohamad Hassan Hamadelnil Deifalla[1, *], **Gurashi Abdalla Gasmelseed**[2]

[1]Chemical Engineering Department, Sudan University of Science and Technology, Khartoum, Sudan
[2]Chemical Engineering Department, University of Science and Technology, Khartoum, Sudan

Abstract

Effective temperature control in continuous stirred-tank reactors (CSTRs) is essential for maintaining product quality and process stability in nonlinear chemical systems. Traditional PID controllers, tuned via Ziegler-Nichols (ZN) methods, often struggle to manage the nonlinearities of such systems, leading to high overshoot, prolonged settling times, and suboptimal disturbance rejection. This study introduces a genetic algorithm (GA)-based approach for optimizing PID controller parameters to enhance the performance of temperature control during the saponification of ethyl acetate in a CSTR, a mildly exothermic reaction characterized by second-order kinetics. The proposed method employs the integral of time-weighted absolute error (ITAE) as a fitness function to iteratively minimize system error and optimize controller gains. Comparative analysis with the ZN-tuned PID controller reveals substantial improvements using the GA-tuned PID controller, including a reduction in overshoot from 61.4% to 38.1%, and decreases in rise, peak, and settling times by 29.7%, 35.3%, and 72.02%, respectively. Additionally, the GA-PID controller demonstrates superior set-point tracking and robust disturbance rejection, achieving a system error reduction of 68.1% compared to the ZN-PID controller. These results underscore the efficacy of genetic algorithms in overcoming the limitations of conventional tuning methods for nonlinear systems. The GA-based tuning approach not only enhances control accuracy and stability but also offers a scalable solution for optimizing complex industrial processes, paving the way for advancements in chemical reactor control and broader applications in process engineering.

Keywords

PID Controller, CSTR, Ziegler-Nichols, Genetic Algorithm, Tuning, Optimization

1. Introduction

Controlling numerous industrial processes presents challenges due to their intrinsic nonlinear nature, limitations on input, and the lack of sufficient measurement data [1-4]. Chemical reactors present significant control challenges due to their nonlinearity [5]. These dynamic behaviors may exhibit strong nonlinearity, complex oscillations, or chaos. Generally, fluctuations in reaction temperature affect conversion, thus influencing the desired product quality. Product quality is ensured through effective temperature control, irrespective of whether the reaction is exothermic, endothermic, or influenced by external heat disturbances. Continuous stirred tank reactors (CSTRs) are fundamental components in the chemical process industry, known for their highly nonlinear behaviors and operation over broad ranges [6]. Figure 1 shows a physical diagram

*Corresponding author: mohammed.hassan.eng@gmail.com (Mohamad Hassan Hamadelnil Deifalla)

Received: 5 November 2024; **Accepted:** 20 December 2024; **Published:** 31 December 2024

for controlling temperature of a jacketed CSTR.

Proportional-integral-derivative (PID) controllers are the most commonly employed controllers in industrial field due to their simplicity and robustness [4, 6]. PID tuning remains a challenging problem [7, 8]. Consequently, conventional PI or PID control methods are inadequate due to their limited effectiveness in nonlinear systems [9]. However, various tuning methods are available that provide accurate solutions. Optimal control performance can be achieved in process control systems by PID-controller Precise tuning parameters [10]. According to Seborg [11], The most effective controller is the one that delivers optimal performance with minimal overshoot. A heuristic method for PID controller tuning, commonly known as the ultimate sensitivity or trial-and-error method, was developed by Ziegler and Nichols [12]. In this method, proportional feedback control is applied to the plant, with the proportional gain incrementally increased until the closed-loop system reaches a state of marginal stability, marked by continuous oscillations [13, 14]. Nonlinear CSTR systems exhibit complex behaviors such as time-varying delays and frequency response curves that traditional ZN-tuned PIDs struggle to handle [15, 16]. The Ziegler-Nichols tuning method, limited by its quarter decay ratio loop tuning, often results in increased overshoot, rise and settling times, particularly in nonlinear and complex systems such as CSTRs [17, 18]. In contrast to traditional optimization techniques, Genetic Algorithms (GA) offer a promising alternative for tuning PID controllers in these nonlinear settings by iteratively selecting and refining parameter values, which allows it to adapt to nonlinearities more effectively. This characteristic renders GAs particularly effective for minimizing performance metrics, including overshoot, rise, settling times, and system error [19].

The ethyl acetate hydrolysis with sodium hydroxide to form sodium acetate and ethanol is shown as [20]:

$$CH_3CO_2C_2H_5 + NaOH \rightarrow C_2H_5OH + CH_3CO_2Na \quad (1)$$

This reaction is equi-molar, irreversible and non-catalytic, taking place in a constant-density system. It occurs in a homogeneous phase and is mildly exothermic in nature. The reaction is first-order with respect to both sodium hydroxide and ethyl acetate, and second-order overall [21]. The rate constant and reaction kinetics for the ethyl acetate hydrolysis are as follows [20]:

$$-r_{NaOH} = k\, C_{NaOH}\, C_{EtAC} \quad (2)$$

Vilanova and Visioli [22], provided an extensive analysis of several PID tuning strategies, encompassing process reaction curve techniques, performance criterion optimization, direct synthesis methods, robustness evaluation, and tuning based on ultimate cycle principles. Martins [23], described the utilizing of MATLAB/SIMULINK in PID controller tuning using ITAE index. Ahmed and Esmaeel [24], designed and evaluated a fuzzy logical temperature controller for ethyl acetate sapoinfication in a CSTR. They found the fuzzy logical controller showed excellent performance compared to PID control. Mousa and Dawood [25], studied the temperature and concentration control of ethyl acetate saponification by comparing methods of Ziegler-Nichols, Chien-Hrones-Reswick and Cohen-coon with fuzzy logic and neural network tuning methods. They found fuzzy logic control showed better performance - overshoot and settling time. Sujatha and Panda [26], analysed the tuning of IMC controller for three non-square MIMO systems. They investigated the control of ethyl acetate saponification in a CSTR for temperature and pH. Deifalla [27], studied the simulation and conventional temperature control of ethyl acetate saponification in a CSTR using ZN-PID controller. Deifalla et al [20], investigated the system transfer functions and cascade control temperature for ethyl acetate saponification in a CSTR. They used two conventional ZN-PID controllers for adjusting the CSTR temperature.

This study aims to optimize PID temperature controller performance in a CSTR during ethyl acetate saponification by enhancing overshoot, settling, and rise times through genetic algorithm tuning. It compares these results with the traditional Ziegler-Nichols method, which often results in higher overshoot and longer settling and rise times, to improve system stability, responsiveness, and product quality in nonlinear processes.

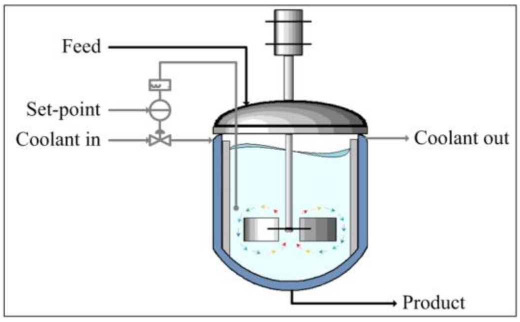

Figure 1. *Conventional Feedback Temperature Control for a CSTR [27].*

2. Methods

2.1. Model of CSTR Temperature Control

The ethyl acetate saponification system transfer functions, ultimate and Ziegler-Nichols tuning parameters were obtained from Deifalla [27]. The system model was developed in SIMULINK, including regulating, process control, and measurement elements. Furthermore, a MATLAB m-file is developed to define the fitness function for computing the ITAE index as fitness function. Moreover, the Genetic algorithm function in MATLAB optimization toolbox is used to minimize the ITAE index and optimize controller parameters. The controller transfer function$G(s)$, is given as [28]:

$$G(s) = \frac{P(s)}{\varepsilon(s)} = k_c\left(1 + \tau_d s + \frac{1}{\tau_i} s\right) \quad (3)$$

where k_c, τ_I, and τ_d are adjustable and need to be optimized to achieve the desired set-point. The transfer functions for the process and the valve element as [27]:

$$G_p = \frac{74.52}{(0.87s+1)(0.15s+1)} \tag{4}$$

$$G_v = \frac{0.028}{25.67s+1} \tag{5}$$

$$G_m = 1 \tag{6}$$

ITAE is defined as [29]:

$$\text{ITAE} = \int_0^\infty t|e(t)|dt \tag{7}$$

Where $e(t)$ represents the system error, which is the difference between the set-point $y_{sp}(t)$ and the controlled variable $y(t)$, with t denoting time.

2.2. Genetic Algorithm

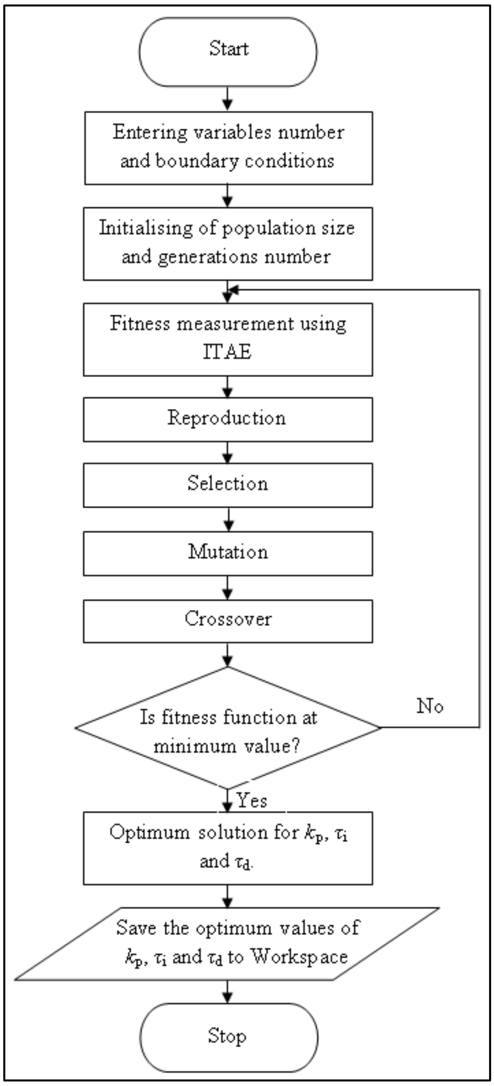

Figure 2. *GA-based Optimization for PID tuning Flowchart.*

Genetic algorithms are optimization techniques inspired by biological evolution, employing selection, crossover, and mutation to explore solution spaces effectively, particularly in complex and non-linear problems [30]. The GAs inspired by Darwin's theory of evolution, which posits that the survival of the fittest [31]. GA enhances process stability and response in nonlinear dynamics by efficiently searching for optimal control parameters. The GA steps for tuning PID controller are shown in Figure 2.

2.3. Fitness Function

Fitness function utilized in the GA for PID tuning is based on the system error between set-point and measured value. PID tuning optimization can be performed by minimizing the integral time absolute error (ITAE), which ensures enhanced system performance by prioritizing long-term system error reduction [32]. GA tunes PID controllers by minimizing a fitness function, optimizing controller parameters. However, the controller ensures to reaches the desired state within time (t) [33]. Whereby, the fitness function becomes [32]:

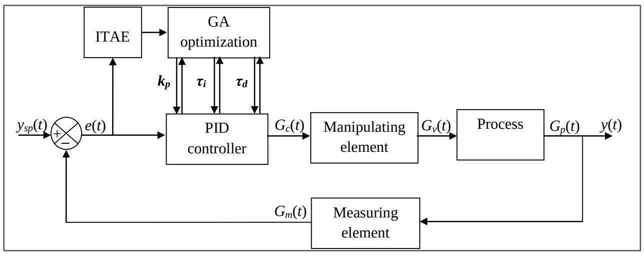

Figure 3. *feedback closed-loop system with GA-based Optimization for PID tuning.*

$$\text{Minimize } f(k_c, \tau_i, \tau_d) = \int_0^t t\left|y_{sp}(t) - y(t)\right| dt \tag{8}$$

Figure 3 shows feedback control system with GA-based model to optimize PID controller parameters. Both GA-PID and ZN-PID controller performances were evaluated using set-point tracking and disturbance rejection using SIMULINK models. Initial parameters used in GA were shown in Table 1. Deifalla [27], reported that the system is stable for all values of gains. Therefore, the boundary constraints are selected between ultimate and Ziegler-Nichols parameters as shown in Eq. (9) and Table 2, respectively.

$$\text{Boundary constraints} = \begin{cases} K_U \geq k_p \geq k_{c_{ZN}} \\ 1/P_U \leq 1/\tau_i \leq \tau_{i_{ZN}} \\ P_U \geq \tau_d \geq \tau_{d_{ZN}} \end{cases} \tag{9}$$

Table 1. *GA Parameter for the CSTR.*

Parameter	Value
Variables number	3
Population Size	50
Selection	Uniform
Mutation	Uniform
Crossover	Single point
Generations	100

Table 2. *PID-Controller Parameters Ranges.*

Parameter	Ultimate		Ziegler-Nichols		
	K_U	P_U	$k_{c_{ZN}}$	$\tau_{i_{ZN}}$	$\tau_{d_{ZN}}$
Value	99.770	2.240	59.862	1.120	0.278

Table 3. *Parameters of the GA-PID controller.*

Controller Parameters	GA-PID
kc	96.946
τi	1.676
τd	0.378

3. Results

To optimize the parameters of the PID temperature controller for a CSTR during the saponification of ethyl acetate by minimizing the ITAE using GA, a SIMULINK model was developed as shown in Figure 4. The PID parameters obtained using the Ziegler-Nichols and GA methods are showed in Table 3.

The unit step change output response and performance characteristics for the systems under ZN-PID and GA-PID controllers showed in Figure 5 and Table 4 for the closed-loop.

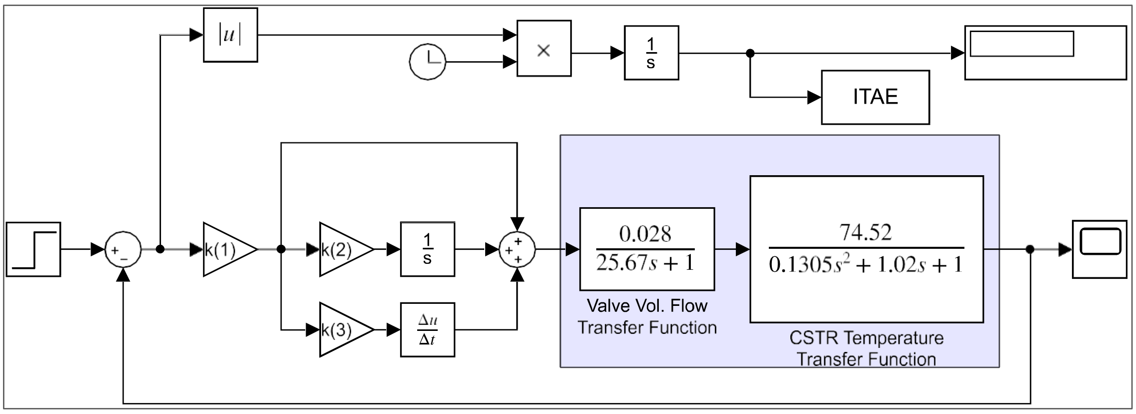

Figure 4. *SIMULINK model for PID tuning using ITAE performance index.*

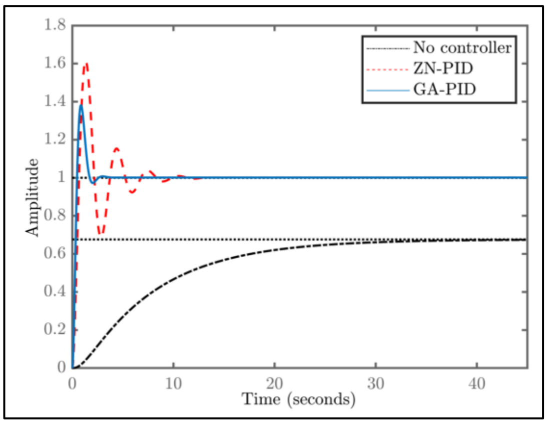

Figure 5. *Step Change Response Using ZN-PID and GA-PID Controllers for the Closed-loop.*

Table 4. *The System Error Values Calculated by ITAE Index.*

Controller type	ITAE value
Without controller	33.275
ZN-PID	3.514
GA-PID	1.120

Table 5 shows the system error values calculated by ITEA index, which is remarkably reduced the system error compared to ZN-PID controller.

Table 5. Characteristics of the Closed-Loop Step Response.

Characteristic	No controller	ZN-PID	GA-PID
Overshoot (%)	-	61.400	38.100
Peak amplitude	-	1.610	1.380
Peak time (s)	-	1.320	0.854
Rise time (s)	16.800	0.458	0.322
Settling time (s)	30.700	7.970	2.230
Final value	0.676	1.000	1.000

Figure 6 shows a multiple set-point was implemented in the system tuned by both Z-N and GA methods.

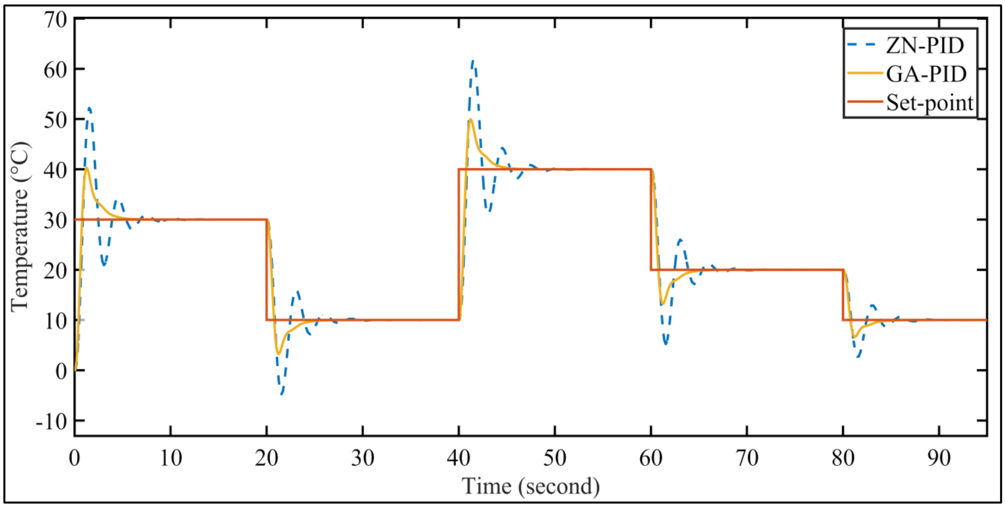

Figure 6. Comparison of Set-point tracking between ZN-PID and GA-PID Controller Performances.

Figure 7. shows SIMULINK block diagram illustrating the disturbance rejection performance of the closed-loop system regulated by a PID controller.

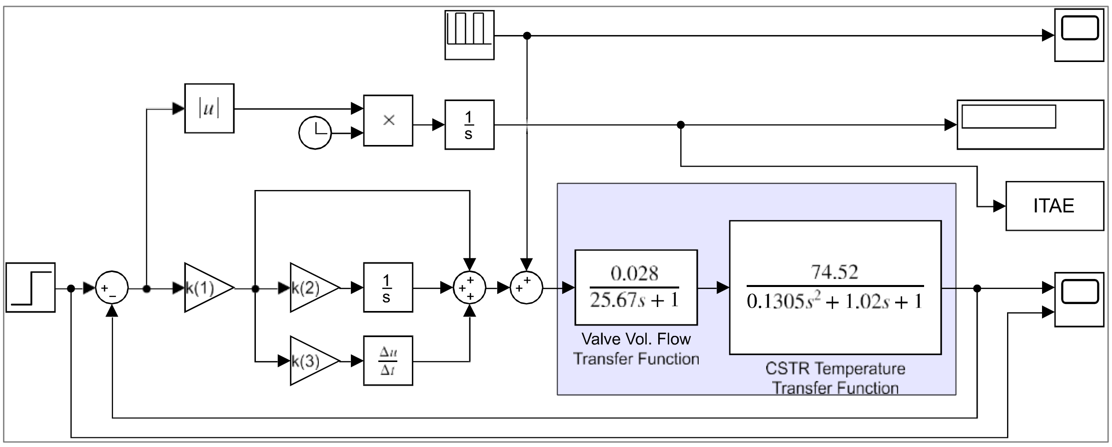

Figure 7. SIMULINK Block Diagram of Disturbance Rejection Subjection to the Closed-loop System with PID-Controller.

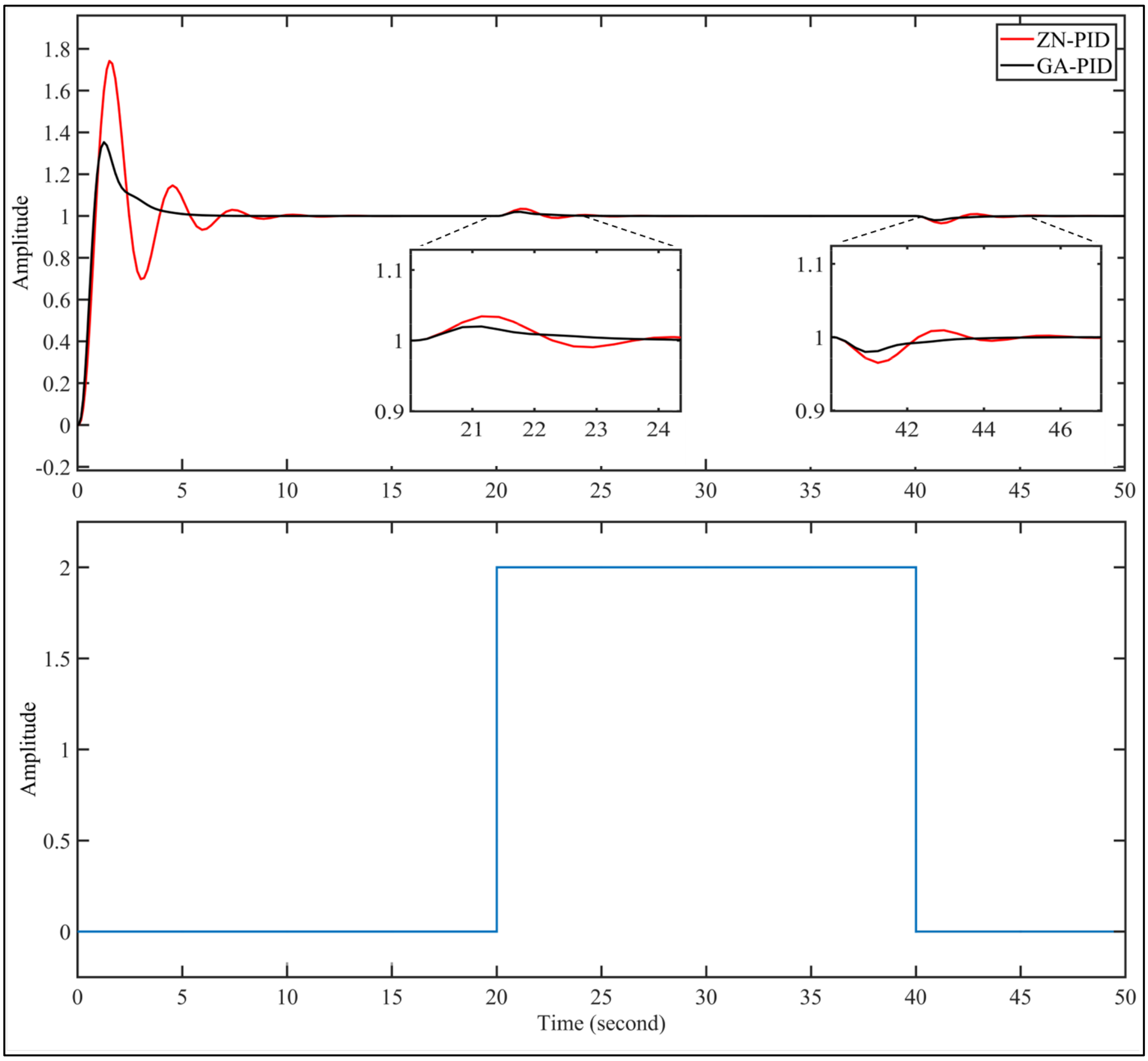

Figure 8. *Step Responses of ZN-PID and GA-PID Controllers Subjected to Disturbance.*

4. Discussion

Table 4 shows the system error values evaluated using the ITAE index for different controllers. The data reveal a significant reduction in system error with the implementation of advanced control strategies. Specifically, the system operating without a controller exhibits the highest ITAE value of 33.275, indicating poor error performance. The ZN-PID controller improves performance considerably, reducing the ITAE value to 3.514. Further enhancement is achieved with the GA-PID controller, which yields the lowest ITAE value of 1.120, demonstrating its superior capability in minimizing system error.

Meanwhile, GA-PID controller implementation on the CSTR temperature control system results in an enhanced system response with respect to control performance and disturbance rejection.

Figure 6 clearly shows that the GA-tuned PID controller achieves excellent performance in tracking multiple set-points compared to ZN-PID controller in terms of minimum overshoot and faster responsiveness. The GA-PID controller exhibited superior performance compared to the ZN-PID controller, achieving significantly shorter settling time, peak time, and rise time. Moreover, the GA-PID controller achieves lower overshoot than the ZN-PID controller. The system response exhibited a deviation from the desired value of 1.00. The ZN-PID controller reached a steady state at 12 s, while the GA-PID controller achieved stability within 3 s by minimizing system error. Obviously, GA-PID controller provides fast response to stability compared to ZN-PID controller.

Table 5 shows that the GA-PID controller provides substantial improvements, reducing overshoot from 61.4% to 38.1% and lowering both settling and rise times by 27.7% and 72.02%, respectively. Furthermore, GA-PID controller decreased the peak time about 35.3% compared to ZN-PID controller.

Disturbance rejection characteristics describe the capability of the system to return to the desired target temperature when subjected to external disturbances. A SIMULINK model was developed to evaluate ZN-PID and GA-PID controllers performance under disturbance subjection as shown in Figure 7.

Figure 8 shows the responses of ZN-PID and GA-PID controllers when 2 amp of disturbance subjected to the system. Remarkably, GA-PID controller response was faster than ZN-PID, rejected the disturbance more effectively. Whereby, GA-PID controller can achieve adaptability to nonlinearity and robustness to disturbances.

Moreover, the system error on ZN-PID controller was 3.514, while on GA-PID was 1.120 as shown in table 4. This confirms the minimization in system error achieved through the application of the GA using ITAE index.

As demonstrated in this research, by minimizing the ITAE index, the GA-based approach ensures precise control and robust performance across diverse operating conditions. This trend underscores the effectiveness of optimization-based PID tuning in achieving robust disturbance rejection and enhanced system stability.

5. Conclusions

In this study, the performance of a PID controller for temperature control in a continuous stirred-tank reactor (CSTR) during ethyl acetate hydrolysis was optimized through a genetic algorithm (GA) tuning method. Comparisons were made with the traditional Ziegler-Nichols (ZN) tuning approach, revealing that the GA-tuned PID controller achieved superior performance across multiple metrics. Specifically, overshoot was reduced from 61.4% to 38.1%, while rise, peak, and settling times were decreased by 29.7%, 35.3%, and 72.02%, respectively. By minimizing the ITAE index to 68.1% of the ZN-PID system error, the GA method effectively lowered system error and enhanced overall system stability. The GA-PID controller demonstrated faster set-point tracking, lower overshoot, and improved disturbance rejection, resulting in more reliable and accurate reactor temperature control. Consequently, the GA-based tuning approach enhances control performance in nonlinear chemical processes, such as CSTRs, establishing it as a valuable alternative to conventional tuning methods. These findings indicate that the application of genetic algorithms for PID parameter optimization in complex and nonlinear systems holds substantial potential for improving process efficiency and maintaining product quality in industrial contexts.

Abbreviations

PID	Proportional Integral Derivative
CSTR	Continuous Stirred Tank Reactor
ZN	Ziegler-Nichols
ITAE	Integral Time Absolute Error
K_U	Ultimate Gain
P_U	Ultimate Period
G_p	Process Transfer Function
G_v	Valve Transfer Function
G_m	Thermocouple Transfer Function
t	Time
k_p	Proportional Term of Controller
τ_i	Integral Term of Controller
τ_d	Derivative Term of Controller

Author Contributions

Mohamad Hassan Hamadelnil Deifalla: Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft

Gurashi Abdalla Gasmelseed: Supervision, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] M. Kumar and R. Singh, Comparison of non-linear, linearized 2nd order and reduced to FOPDT models of CSTR using different tuning methods, Resource-Efficient Technologies, 2016, 2(1), pp. S71-S75. https://doi.org/10.1016/j.reffit.2016.11.003

[2] F. Wallam and A. Y. Memon, A robust control scheme for nonlinear non-isothermal uncertain jacketed continuous stirred tank reactor, Journal of Process Control, 2017, 51(1), pp. 55-67. https://doi.org/10.1016/j.jprocont.2016.11.001

[3] B. Tandon, S. Narayan, and J. Kumar, Nonlinear disturbance observer based robust control for continuous stirred tank reactor, ICIC Express Letters, 2018, 12(1), pp. 1-7. https://doi.org/10.24507/icicel.12.01.1

[4] G.-B. So and G.-G. Jin, Fuzzy-based nonlinear PID controller and its application to CSTR, Korean Journal of Chemical Engineering, 2018, 35(4), pp. 819-25. https://doi.org/0.1007/s11814-017-0329-1

[5] L. Suo, J. Ren, Z. Zhao, and C. Zhai, Study on the nonlinear dynamics of the continuous stirred tank reactors, Processes, 2020, 8(11), pp. 1436. https://doi.org/10.3390/pr8111436

[6] M. Manimozhi and R. Meenakshi, Multiloop IMC-based PID controller for CSTR process, in Proceedings of the International Conference on Soft Computing Systems: ICSCS 2015, Volume 1, 2016, pp. 615-25. https://doi.org/doi.org/10.1007/978-81-322-2671-0_59

[7] A. Ambroziak and A. Chojecki, The PID controller optimisation module using Fuzzy Self-Tuning PSO for Air Handling Unit in continuous operation, Engineering Applications of Artificial Intelligence, 2023, 117(105485), pp. 1-14. https://doi.org/10.1016/j.engappai.2022.105485

[8] S. Benameur, S. Tadrist, M. A. Mellal, and E. J. Williams, Optimization of PID controller: A brief overview, in Trends, Paradigms, and Advances in Mechatronics Engineering, IGI Global, 2023, pp. 1-16. https://doi.org/10.4018/978-1-6684-5887-7.ch001

[9] W. Wu, Nonlinear bounded control of a nonisothermal CSTR, Industrial & engineering chemistry research, 2000, 39(10), pp. 3789-98. https://doi.org/10.1021/ie990186e

[10] V. Dubey, H. Goud, and P. C. Sharma, Role of PID control techniques in process control system: a review, presented at the Data Engineering for Smart Systems: Proceedings of SSIC 2021, 2022, pp. 659-70. https://doi.org/10.1007/978-981-16-2641-8_62

[11] D. E. Seborg, T. F. Edgar, D. A. Mellichamp, and F. J. Doyle III, Process dynamics and control, fourth ed., John Wiley & Sons, USA, 2017.

[12] J. G. Ziegler and N. B. Nichols, Optimum settings for automatic controllers, Transactions of the American society of mechanical engineers, 1942, 64(8), pp. 759-65. https://doi.org/10.1115/1.4019264

[13] B. G. Liptak, Instrument Engineers' Handbook, Vol. Two: Process Control and Optimization, CRC Press, 2018. https://doi.org/10.1201/9781315219028

[14] R. S. Esfandiari and B. Lu, Modeling and analysis of dynamic systems, CRC Press, 2018. https://doi.org/10.1201/b22138

[15] X. Shi, H. Zhao, and Z. Fan, Parameter optimization of nonlinear PID controller using RBF neural network for continuous stirred tank reactor, Measurement and Control, 2023, 56(9-10), pp. 1835-43. https://doi.org/10.1177/00202940231189307

[16] X. Sun, N. Liu, R. Shen, K. Wang, Z. Zhao, and X. Sheng, Nonlinear PID controller parameters optimization using improved particle swarm optimization algorithm for the CNC system, Applied Sciences, 2022, 12(20), pp. 10269. https://doi.org/10.3390/app122010269

[17] E. Joseph and O. Olaiya, Cohen-coon PID tuning method; A better option to Ziegler Nichols-PID tuning method, ENginerring Research, 2017, 2(11), pp. 141-45.

[18] M. Chidambaram and N. Saxena, Relay tuning of pid controllers for unstable MIMO processes, Springer Nature, Singapore, 2018. https://doi.org/10.1007/978-981-10-7727-2

[19] K. Saadaoui, A. Moussa, and M. Benrejeb, PID controller design for time delay systems using genetic algorithms, The Mediterranean Journal of Measurement and Control, 2009, 5(1), pp. 31-36.

[20] M. H. H. Deifalla, G. A. Gasmelseed, and A. A. Mohammed, Transfer function identification and control of ethyl acetate hydrolysis in a cstr using ASPEN HYSYS and MATLAB, International Journal of Engineering Applied Sciences and Technology (IJEAST), 2024, 8(12), pp. 44-56.

[21] M. H. H. Deifalla, G. A. Gasmelseed, and A. A. Mohammed, Simulation of ethyl acetate hydrolysis in a CSTR using Aspen HYSYS software, International Journal of Engineering Applied Sciences and Technology (IJEAST), 2024, 8(12), pp. 57-63.

[22] R. Vilanova and A. Visioli, PID control in the third millennium vol. 75, Springer, 2012. https://doi.org/10.1007/978-1-4471-2425-2

[23] F. G. Martins, Tuning PID controllers using the ITAE criterion, International Journal of Engineering Education, 2005, 21(5), pp. 867.

[24] D. F. Ahmed and M. N. Esmaeel, Fuzzy logic control of continuous stirred tank reactor, Tikrit Journal of Engineering Sciences, 2013, 20(2), pp. 70-80. https://doi.org/10.25130/tjes.20.2.07

[25] K. M. Mousa and Z. E. Dawood, Study on control of CSTR using intelligent strategies, Al-Nahrain University, College of Engineering Journal (NUCEJ), 2015, 18(2), pp. 294-303.

[26] V. Sujatha and R. C. Panda, Time domain modeling and control of complex non-linear chemical processes using relay feedback test, Transactions of the Institute of Measurement and Control, 2020, 42(15), pp. 2885-907. https://doi.org/10.1177/0142331220931968

[27] M. H. H. Deifalla, Simulation and control of CSTR for ethyl acetate hydrolysis using Aspen HYSYS and MATLAB, M.Sc thesis, University of Science and Technology, Khartoum, 2020.

[28] G. A. Gasemseed, A textbook of chemical engineering process control, 3rd ed., G-Town Center, Khartoum, Sudan, 2016, pp. 66-164.

[29] C. S. Rao and S. Santosh, Tuning optimal PID controllers for open loop unstable first order plus time delay systems by minimizing ITAE criterion, IFAC-PapersOnLine, 2020, 53(1), pp. 123-28. https://doi.org/10.1016/j.ifacol.2020.06.021

[30] S. Mirjalili, Generic Algoritm. In Evolutionary algorithms and neural networks: Theory and applications, vol 780, 2019, pp. 43–55. https://doi.org/10.1007/978-3-319-93025-1_4

[31] R. R. Gawde, S. P. Jadhav, and B. A. Garg, Design and implementation of soft computing-based robust PID controller for CSTR, in Proceedings of International Conference on Computational Intelligence and Emerging Power System: ICCIPS 2021, 2022, pp. 301-17. https://doi.org/10.1007/978-981-16-4103-9_26

[32] H. Goud and P. Swarnkar, Analysis and simulation of the continuous stirred tank reactor system using genetic algorithm, in Harmony Search and Nature Inspired Optimization Algorithms: Theory and Applications, ICHSA 2018, 2019, pp. 1141-51. https://doi.org/10.1007/978-981-13-0761-4_106.

[33] M. Pietrala, Sliding mode control with minimization of ITAE and the input signal limitation, in Conference on Automation, 2021, pp. 75-84. https://doi.org/10.1007/978-3-030-74893-7_8

Biography

Mohamad Hassan Hamadelnil Deifalla is a senior lecturer in Chemical Engineering Department, Sudan University of Science and Technology. He received his B.Sc and M.Sc in chemical engineering from Sudan University of Science and Technology and University of Science and Technology, respectively. He also received his Ph.d degree in chemical engineering from Karary University. His current research interests include processes optimization, modeling simulation and control of processes, kinetics and reactor design.

Gurashi Abdalla Gasemelseed is a professer in Department of Chemical Engineering, Faculty of Engineering, University of Science and Technology, Khartoum, Sudan. He received his B.Sc and M.Sc degrees in chemical Engineering from University of Khartoum. He also received a Diploma in Leather Technology from Northamton Collage of Technology, UK, and Ph.D in Chemical Engineering from Aston University in Birmingham, UK. His current research interests include design, modeling, simulation, and control of chemical process, tannery waste treatment, design of petroleum and petrochemical processes.