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Research Article

Design and monitoring of control system for Amylolytic Enzymes Production with Conventional Controller and Fuzzy Logic

Dg Nurdayana Azman, Abd Rahman^{*}, N and Mohd Ali, J

Department of Chemical Engineering and Process, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), 43650, Bandar Baru Bangi, Selangor, MALAYSIA

^{*}Corresponding Author: norlizajkkp@ukm.edu.my

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Abstract: Amylolytic enzymes is a starch hydrolyzing enzyme that has been used in wide range industrial processing. The demand for amylolytic enzymes has been increase for the past year, thus, highly efficient processing for amylase production is required. In most bioprocessing, process control and monitoring are crucial since this process are highly sensitive. To date, the study on process control for amylase production has not been extensively explore. Since bioprocess involve a complex system and highly non-linear, the use of conventional controller is limited. With the advancement in process control by integrating Artificial Intelligence has open bigger area for process control study in bioprocessing field. In this study, process control and monitoring system for amylase production was designed to control pH and temperature by using PID and Fuzzy Logic controller. The methods of designing the control system involves several steps from choosing unit operation to performing controller simulation. Both PID and Fuzzy Logic controller are designed and simulated in MATLABs and compared using step response. The result show that both controller able to achieve steady state and stable at desired set point. However, FL shows better response in term of shorter rise and settling time without overshoot.

Keywords: Amylolytic enzymes, Process control, pH, Temperature, PID controller, Fuzzy Logic Controller.

1. Introduction

Amylolytic enzymes is a starch hydrolyzing enzyme, which reduce starch or related saccharides into sugar [1]. The ability of amylolytic enzymes in starch hydrolysis have high potential in a wide number of industrial process application, mainly starch processing such as in food and beverage for sugar production, production of ethanol, in textile industry to remove starch, and in paper industry, to reduce the viscosity of the natural starch for paper sizing [2]. Currently, the utilization of amylolytic enzymes has extended for applications in waste treatment and bioprocessing [3]. With this expansion and increasing number of starch utilization in industries, highly efficient processing for amylolytic enzymes productions is required.

Amylolytic enzymes are produced from wide range of living system such as animal, plants, and microorganisms [4]. Among these three sources, enzyme production from microorganisms are highly advantages in terms of time and space efficiency, quality and consistency, yield, and ability to control microorganisms in physiological and physio-chemical manner [5]. There are several types of amylase-producing microbes such as *Aspergillus sp.*, *Saccharomycopsis sp.*, *Streptomyces sp.*, *Proteus*, *Bacillus spp.*, *Pseudomonas sp.*, *Escherichia*, and *Lactobacillus* [6]. *Aspergillus* species such as *Aspergillus oryzae* and *Aspergillus niger* produce large variety of enzymes that are used widely in industry including amylase.

A. oryzae has the ability to produce a vast amount of high value proteins and industrial enzymes, which makes it favorable host for the production of heterologous proteins [7]. On the other hand, *A. niger* has significant hydrolytic capacities in amylase production and high tolerance to acidic conditions, which help to avoid contamination [8]. Other *Aspergillus spp* strains that commonly used for commercial production of amylase are *A. awamori* and *A. fumigatus*. *Aspergillus spp* has been dominantly used in industrial scale production of amylase via fermentation process.

In fermentation process, process control and monitoring are crucial to ensure process efficiency and safety. Process control parameters, such as temperature, pH, moisture content, and incubation period, has been studied for its impact on the production of amylolytic enzymes [9]. Temperature, pH, and moisture content plays an important role in amylase production as it influences the metabolic activities rate of microbe, thus affect rate of microbial growth and stability of enzymes production [10]. While incubation period does not relate directly to the metabolic activities of the microbe, but it provides duration of optimum growth. Like human, microbe need to be nurtured in an environment that “comfortable” to them in order to obtain their full potential. Hence, precision in process control is necessary for this process.

Process control is the ability to monitor and adjust a process to give a desired output [11]. Before process control and automation, process parameters are adjusted by plant operators manually (open loop process control). It may sound easy and straightforward; however, it has limitations in dealing with complex unit operations, occurrence of human error and quality of control action [12]. The development of closed loop process control, result in emergence of automatic control strategy that overcome the limitations of manual controlling.

In automatic process control, the controller is the brain of the system as it responsible for control action to maintain and kept the desired process values. They are divided into two categories: Conventional controller and Advanced controller. Controller such as On/Off, and Continuous Controller (Proportional (P), Integral (I), and Derivative (D) are known as conventional controller, which used classical framework and is commercially used today [13]. Often, PID controller are used as it is considered as the best controller in the control system family. It works by calculating the three errors – P, I and D and control it by responding to how much a process variable deviates from the desired set point values based on the three manners [14]. This type of controller theoretically deals with linear systems having constant parameters and gives good approximation for system that are regulated at fixed operating points [15]. However, the linear constant coefficient approximation will not always be satisfactory when the operating conditions change.

On the other hands, advanced controller such as Fuzzy Logic (FL) and Artificial Neural Network (ANNs), integrate Artificial Intelligence (AI) and inherit classical and modern methods in its framework. Most of the real- world processes are nonlinear systems (varying operating point), thus, making it not suitable for application of conventional control [16]. The nonlinear system or systems with unknown mathematical models can be controlled easily by means of fuzzy algorithms, based on intuition and experience of operators [17]. FL controller has been applied in many electrical appliances such as air conditioner and washing machine [18]. Having linguistic based framework, making it interesting to studies as it is closed to human knowledge compared to others control strategy [19]. FL method that attains the tolerance for imprecision and uncertainty to achieve traceability. It implements decision making functions with helps of IF-THEN rules. There are four principle components of FL controller: (1) Fuzzification Interface, (2) Knowledge base, (3) Decision making logic, and (4) Defuzzification (2) interface [20]. The details of each principle a shown in Table 1.

Table 1. Principles Components of FL controller

COMPONENTS	DESCRIPTIONS
Fuzzification Interface	It measures the values of variables. Then performs a scale mapping that transfers the range of value of input variables into corresponding universe of discourse. Finally, it converts the input data into suitable linguistic values which may be viewed as labels of fuzzy sets
Knowledge Base	It consists of knowledge of application domain and attendant control goals. It consists of a “data base” and “linguistic” (fuzzy) control rule base. 1. Data base: provides necessary definitions for the linguistic control rules and fuzzy data manipulation in an FLC 2. Rule base: consists of control goals and control policy of the domain expects by the means of a set of linguistic control rules.
Decision Making Logic	This is the main component of FLC. It stimulates the human decision making, which is based on the fuzzy concept and capability of inferring fuzzy control action employing fuzzy implication and the rules of inference in fuzzy logic.
Defuzzification Interface	It does scale mapping, for instance, converts the range of values of output variables not corresponding universe of discourse. Defuzzification yields non fuzzy control action from an inferred fuzzy control action

Source: [2]

Currently, the studies of amylase production focus on process optimization, rather than process control and monitoring. This is because there are wide range of source for amylase production, that are still been explore and for each of it the process control parameters may vary. Other than that, process control and modelling of bioprocessing plant is quite difficult due limitation of high nonlinearity effect, large time delay, unknown composition of mixture, uncertainty conditions. Besides that, this process reaction involves microorganisms, which result in highly complex mathematical models. However, recent development of advanced controller design integrating Artificial Intelligence has open a path to improving performance and robustness of process control system in bioprocessing. In this present study, FL controller is selected as advanced controller to control pH and temperature for amylase production, while PID controller were also developed to compare its performance.

The paper is organised as follows. Section 2 present the methodology which covers the case study, mechanistic model development, design and develop conventional control and monitoring system for production of amylolytic enzymes, to design a PID and Fuzzy Logic control system, and to compare the performance of PID controller and Fuzzy Logic controller, followed by the result and discussion in Section 3. Finally, Section 4 concludes this paper.

2. Methodology

In this section, the case study, mechanistic model development, design and develop conventional control and monitoring system for production of amylolytic enzymes, to design a PID and Fuzzy Logic control system, and to compare the performance of PID controller and Fuzzy Logic controller was presented.

2.1. Design of Control System

The design of control system involved the following step, shown in Figure 1 [21]. The first step of designing control system is to choose unit operation (reactor, distillation column) and state any assumption related to it. Then, mathematical models were developed from material and energy balance equation based on the process and unit operation. After that, the control objectives and manipulated variables were stated. To identify the number of control configuration needed for each parameter, the degree of freedom analysis was performed. Then type of controller to be used was be chosen and control parameter was configured (feedback or feedforward). Using Laplace transform, the mathematic models are transformed into transfer function and the simulation model for the process was developed in MATLAB Simulink. Then, the set point was set, and disturbance was introduced to identify the

robustness of process. Finally, the developed control system was simulated, and the performance was displayed.

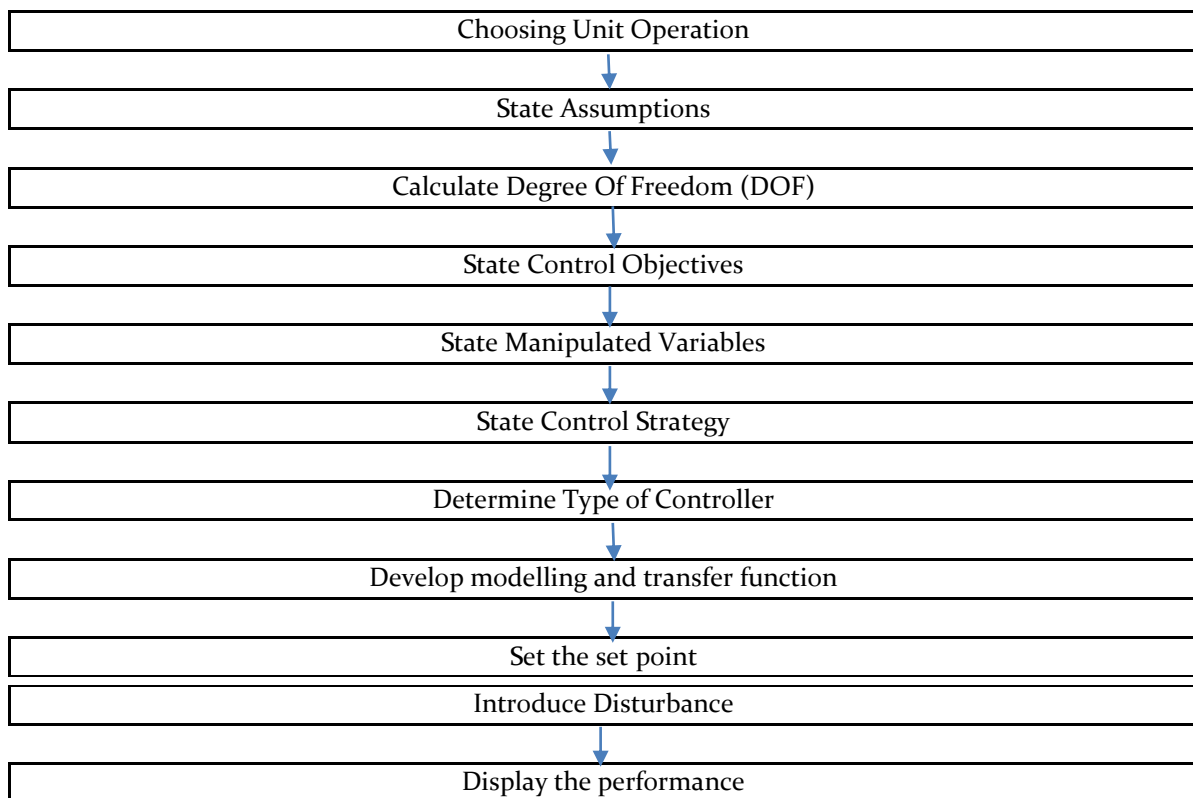


Figure 1. Procedure to evaluate the performance of control system.

Source: [21]

2.2. Design of PID Control System

Figure 2 shows the procedure for designing PID control system. It starts with development of conventional process control system with PID controller in MATLAB (R2021a) Simulink program. The follow by tuning of PID controller. Tuning is a process of obtain the best value of K, I and D, that will give the best performance for PID control. There are several tuning methods, however, for this study the trial-and-error method are used. The procedure of tuning using conventional trial and error method is as follow [22]:

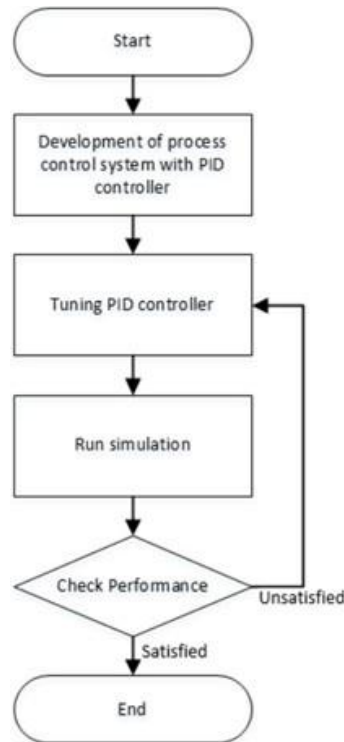


Figure 2. Procedure for designing PID control system

- Step 1: Set K_D and K_I to zero. By trial and error, select K_P that value result in stable oscillatory performance. In multi-input scenario, select value that results in near to critical damping.
- Step 2: Vary K_D with K_P fixed so as to reduce the oscillations and result in reasonable overshoot and settling time.
- Step 3: Vary K_I with K_P and K_D fixed, such that there is zero steady state error in minimum time.

2.2.1. Design of Fuzzy Logic Control System

The flowchart of FL design is shown in Figure 3. The FL controller are designed using Fuzzy Logic Toolbox in MATLAB (R2021a). The method of are referred [23]. Start by entering “fuzzy” in command window. Untitled FIS Editor was opened, with one input labeled **input1**, and output, labeled **output1**. To add additional input, the **Edit** menu was clicked and **Add input** was selected. The default setting use Mamdani Inference method, different inference can be selected from **File** menu. Then membership function was construct in **Membership Function Editor**. Here, the value for **Range** is defined for each input and output. Lastly, rules are defined in **Rule Editor** based

on the input and output MF defined previously. Once the rules are defined, the rules relationship canbe viewed in **Rule Viewer** and **Surface Viewer** window.

The control command rules can be construct based on experimental data. In this study the experimental data was obtained from [24]. The data was tabulated in Table 2 below.

Table 2. Experimental data for the effect of temperature and pH for amylolytic enzymes production

Temperature (°C)	pH	Amylase activity (units/ml)
20	7	20.6271
25	7	30.1950
30	7	26.7159
35	7	23.3053
40	7	13.6815
45	7	2.2638
30	4	21.8050
30	5	40.1351
30	6	35.6178
30	7	34.8359
30	8	20.4151

Source: [24]

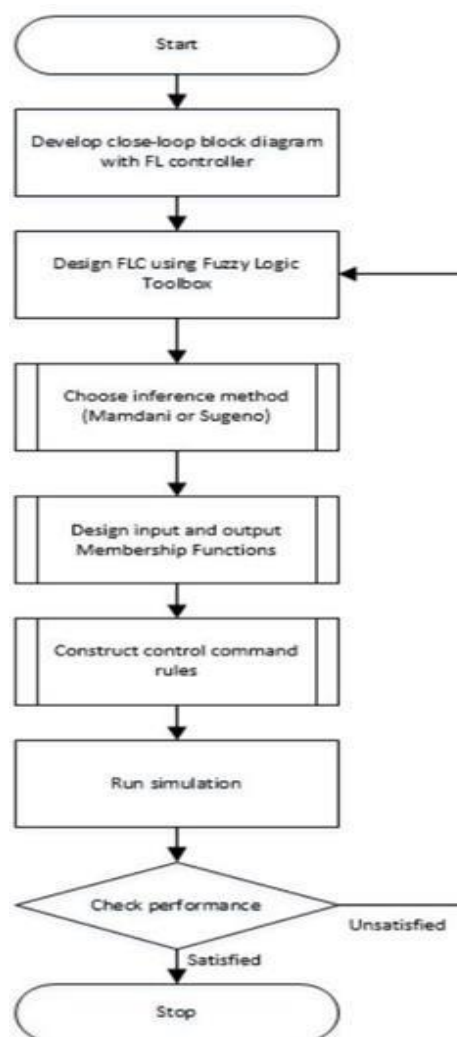


Figure 3. Procedure for designing Fuzzy control system

2.2.2. Comparison for PID Controller and Fuzzy Logic Controller

To compare the performance of both controllers, the develop control systems were connected to a single sink (scope) to enable generating of both responses in one plot. Then data of Rise time, Overshoot, settling time and steady state value was extracted from the plot and compared.

3. Results and Discussion

3.1. Design of Control System

3.1.1. Choosing Unit Operation

In this study, the unit operation that are chosen for the control system is Fermenter (Figure 4). This is where the production of amyolytic enzymes occur. Fermenter is a reactor that commonly used in bioprocessing, which involves organisms or biochemically active substance derived from the organisms. During bioprocessing, biological component are very sensitive to environmental changes inside the reactor and effect the efficiency of the process [25]. The introduction of control system for fermenter can ensure suitable environment for microorganisms' growth, reproduction, and product synthesis at optimum level.

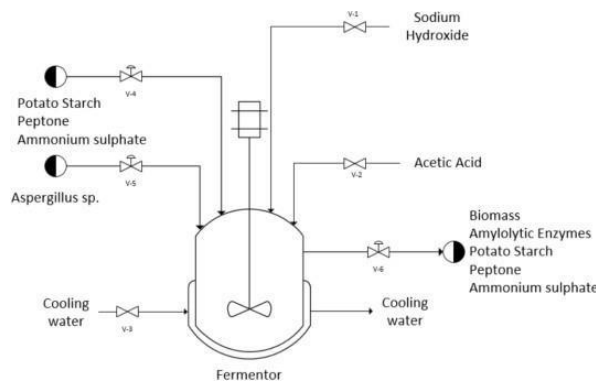


Figure 4. Fermenter

3.1.2. State Assumptions

For this process, there are several assumptions made:

- i. Solution in the reactor is perfectly mixed thus the density and component concentration is constant in the tank and output
- ii. Constant volume in the reactor.
- iii. The speed of stirring is constant
- iv. Mass of metal walls is negligible (no thermal inertia)
- v. Temperature everywhere in jacket is T_j , thus the heat transfer between the process at temperature T and cooling water temperature T_j can be describe by overall heat transfer coefficient

Mathematical model for the system in the fermenter were developed as follow.

Total mass balance,

$$\rho \frac{dV}{dt} = \rho_1 F_1 + \rho_2 F_2 - \rho_3 F_3 \tag{1}$$

Component balance on Potato Starch (A),

$$V \frac{dC_A}{dt} = F_1(C_{A,o} - C_A) - r_A \tag{2}$$

Component balance on Peptone (B),

$$V \frac{dC_B}{dt} = F_1(C_{B,o} - C_B) - r_B \tag{3}$$

Component balance on Ammonia sulphate (C),

$$V \frac{dC_C}{dt} = F_1(C_{C,o} - C_C) - r_C \tag{4}$$

Component balance on Biomass (D),

$$V \frac{dC_D}{dt} = F_2(C_{D,o} - C_D) - F_3 C_D \tag{5}$$

Component balance on Product (E),

$$V \frac{dC_E}{dt} = F_3(C_{E,o} - o) + r_A \tag{6}$$

Energy balance on reactor,

$$\rho C_p V \frac{dT}{dt} = \rho C_p F_3(T_o - T) + \lambda V r_A - UA_H(T - T_j) \tag{7}$$

Energy balance on cooling jacket

$$\rho_j C_{p,j} V_j \frac{dT_j}{dt} = \rho_j C_{p,j} F_j(T_{j,o} - T_j) + UA_H(T - T_j) \tag{8}$$

Component balance on Base solution

$$V \frac{dX_a}{dt} = F_a C_a - (F_a + F_b) X_a \tag{9}$$

Component balance on Acid solution

$$V \frac{dX_b}{dt} = F_b C_b - (F_a + F_b) X_b \tag{10}$$

Calculate Degree of Freedom (DOF)

To determine the regulatable (control) variables within the chemical process, degree of freedom (DOF) analysis need to be conducted. The DOF was conducted following the method presented by [26] as shown in Table 3.

DOF = Number of variables - Number of equations

Table 3. Degree of Freedom (DOF)

Number of variables	17 variables ($F_1, F_2, F_3, V, C_A, C_B, C_C, C_D, C_E, T, T_j, F_a, F_b, C_a, C_b, X_a, X_b$)
Number of equations	10 equations
Number of disturbances	5 (F_1, F_2, F_a, C_A, C_B)
DOF	$17 - 10 - 5 = 2$

State Control Objectives

Based on the DOF, the fermenter requires two control configurations. Hence, there are two control objectives for this study, which are:

- i. To control pH inside the fermenter to set point of pH 5
- ii. To control temperature inside the fermenter to set point of 30°C

3.1.3. Control Configuration (Manipulating Variables and Control Strategy)

Figure 5 shows the P&ID of fermenter for temperature and pH control system.

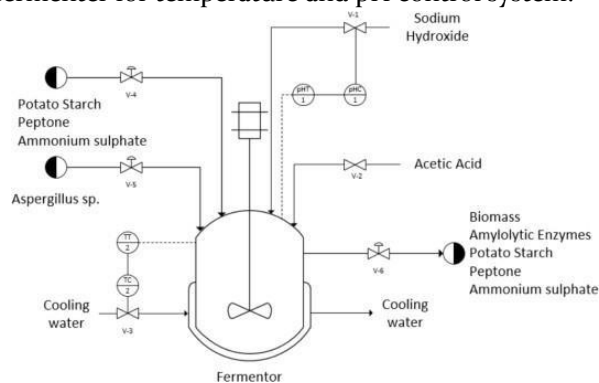


Figure 5. Piping and Instrumental Diagram for Fermenter

For temperature control configuration, the controlled variable is the temperature inside the fermenter, while the manipulated variables are the flowrate of cooling water. From Figure 6, temperature sensor is attached to fermenter to detect any change of temperature in the fermenter. If there is any temperature rises or drop, the sensor will send signal to controller through temperature transmitter. Then the controller, which attached to cooling water valve will increase or decrease the flow of cooling water, to bring back the temperature to set point value.

For pH control configuration, the controlled variable is the pH value, while the amount of NaOH is the manipulated variable. From Figure 5, it shows that pH sensor is attached to the reactor and pH controller is attached to the valve for NaOH. pH probe is used as sensor to detect if there isa decrease or increase in pH value in tank. Then, transmit send the signal to pH controller to increase or decrease the flowrate of alkali solution to the medium, to ensure the pH are back to set point values.

3.1.4 Type of controller

The type of controller that was used are PID controller and Fuzzy Logic controller. These two controllers were compared and discuss in the next section.

3.1.5 Developing Modelling and Transfer Function

The control process was modelled in MATLAB Simulink program following the general block diagram of feedback control system. The first step is to develop transfer function or mathematical model for the process that relates the control variable (input) and manipulated variables(output).

For the temperature system, Equation (7) and (8) are used. The following transfer function was obtained for temperature process:

$$\frac{T_j(s)}{F_1(s)} = \frac{17.45}{0.7478s + 1} \tag{11}$$

$$\frac{T(s)}{T_j(s)} = \frac{2}{2.4938s + 1} \tag{12}$$

For pH system, Equation (9) and (10) are used to obtained dynamic mathematical model on the change of hydrogen ion concentration, Eq. (13). Then the value of pH can be determined by using the Equ (14). The value of variables was obtained from [27] and shown in Table4.

$$V \frac{dx}{dt} = F_a C_a - F_b C_b - (F_a + F_b) X \tag{13}$$

$$pH = -\log_{10}[X + (X^2 + 4K_w)^{0.5}] \tag{14}$$

Table 4. Values of Variables

VARIABLES	VALUE
V	7.4 L
F _a	0.24 L min ⁻¹
F _b	0.1 L min ⁻¹
C _a	0.2 g mol L ⁻¹
C _b	0.1 g mol L ⁻¹

Source: [27]

Figure 6 and Figure 7 shows the process model for pH and temperature control, respectively.

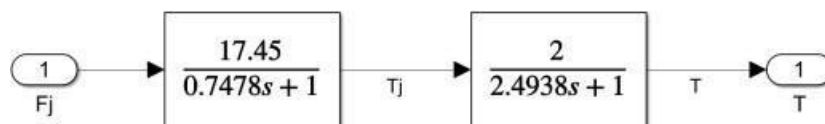


Figure 5. Process Model for Temperature control

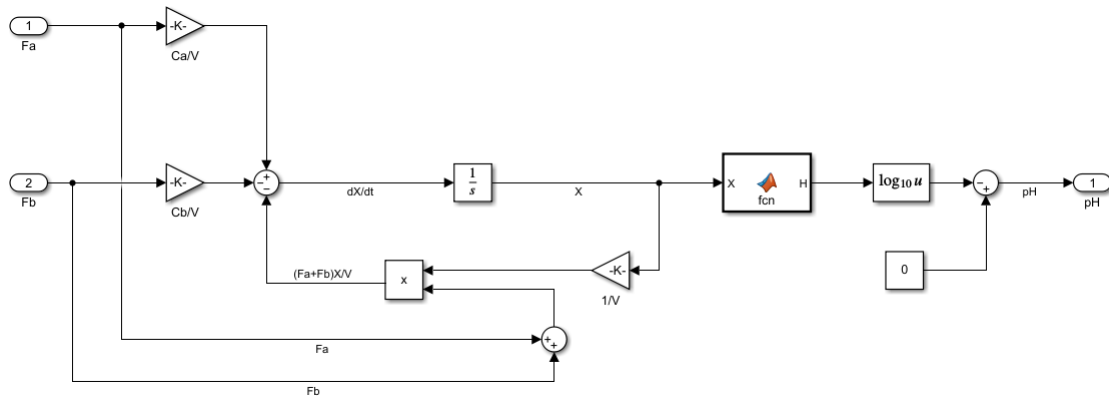


Figure 6. Process Model for pH control

3.2. Design of PID Controller

The plant of the fermentation process is obtained from the modeling in previous section. pH and Temperature control system of fermentation process using conventional feedback based PID controller is shown in Figure 7. The most important thing in PID control is to obtain the optimize value of the proportional gain (KC), integral time (KI) and derivative time (KD). In this study, the optimized value was obtained using trial and-error method. The result for the PID tuning is shown in Table 5 and for temperature control, initial tuning was conducted using P Controller.

Table 5. PID tuning parameter

PARAMETER	PID CONTROLLER		
	KC	KI	KD
pH	1.5	0	2
Temperature	0.2	0	0

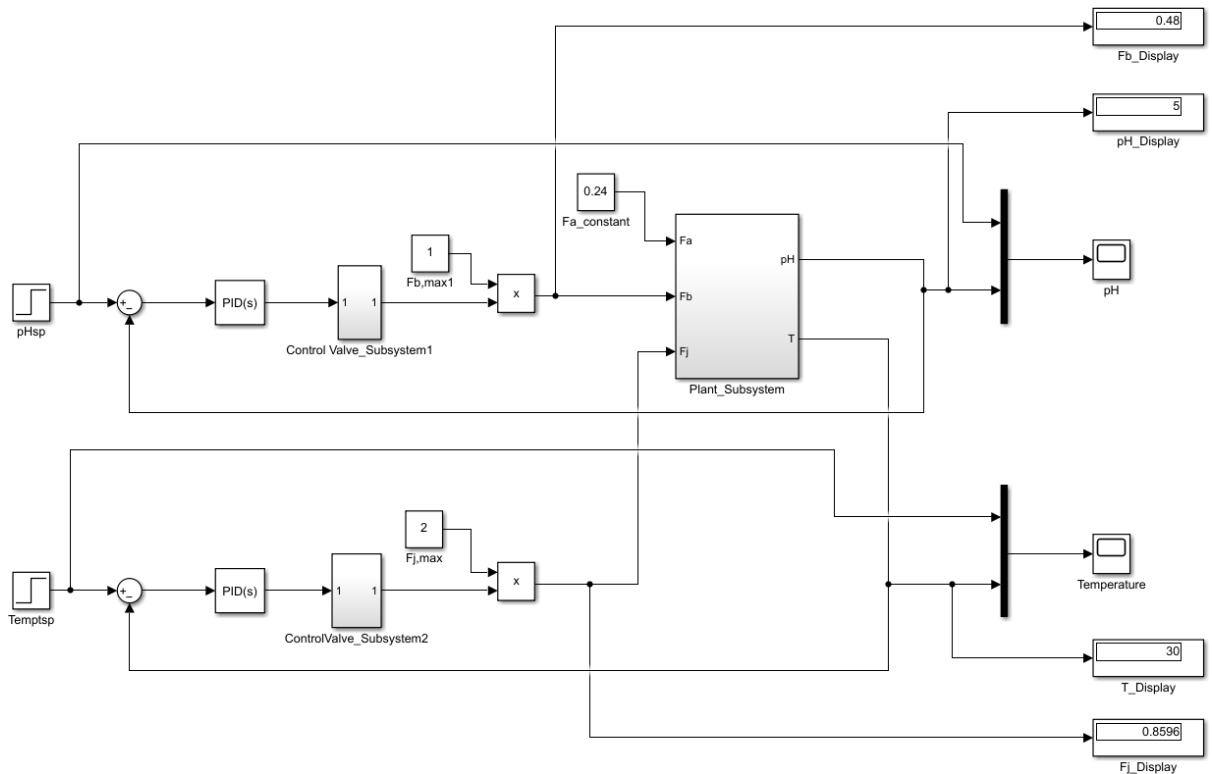


Figure 7. Closed-loop block diagram for temperature control

3.3. Design of Fuzzy Logic Controller

The control system of fermentation process using conventional feedback-based FL controller is shown in FIGURE 8. There is addition of du/dt input before the FL controller. This is because in FL controller, the process error can be extended into rate of error, de/dt . It is the gradient of error that define either error is increasing or decreasing from previous state [27].

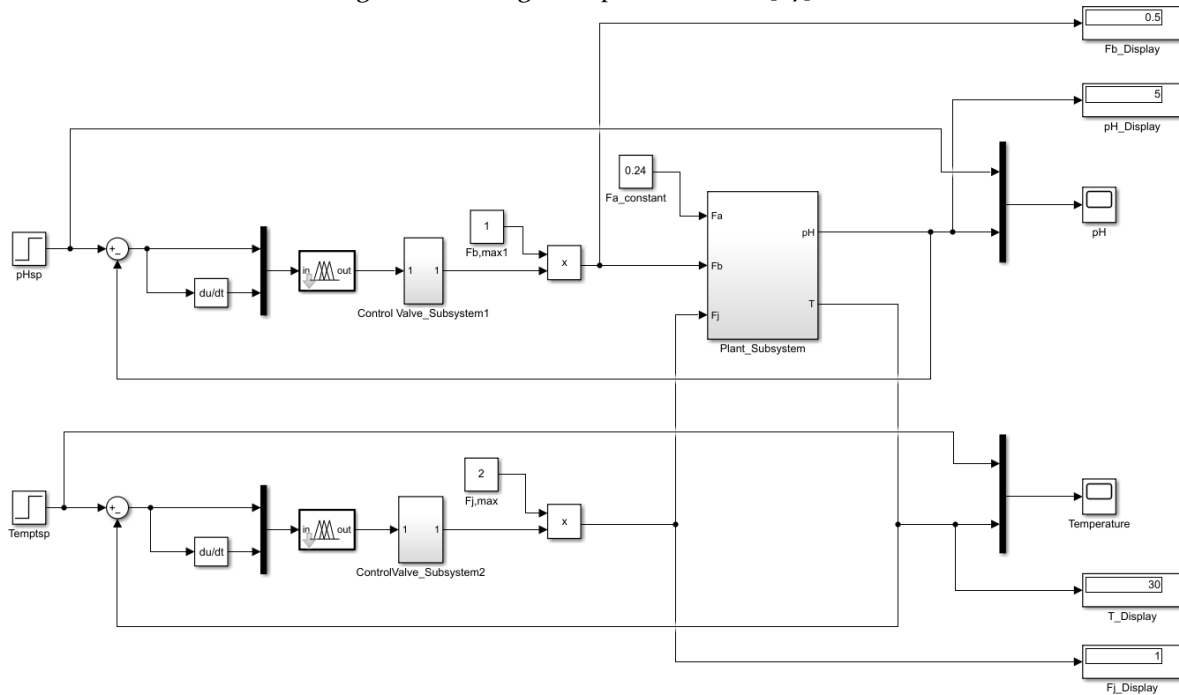


Figure 8. Closed-loop block diagram for temperature control

The first step in FL design is to decide the fuzzy interface that will be used. For this study the mamdani interface are chosen, primarily. Then, the of number input and output were determined, and labelled. Figure 9 and show the input-output for FL control design. The first input is “error”, and second input is rate of error, labelled as “ de/dt ”. While the output is the “Valve_Opening”. In FL, the controller output can be any state of variables like current, voltage, flow rate, heat, etc, but it should be related to manipulated variables [28]. Since the opening of valve is a function of flow rate, then it is chosen as output variables.

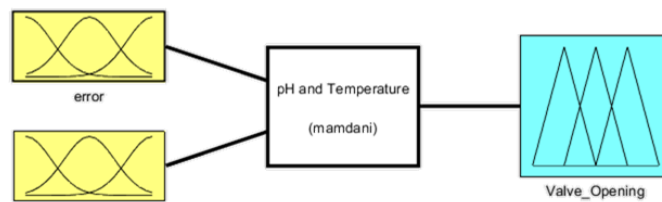


Figure 9. Fuzzy Logic Designer

Next is to define membership function for each input and output variables. Firstly, the range of each variable were defined. Then type of membership function was selected and the range of each MF was defined. For the “error” variables, triangular MF type was used as it is easy to construct and gives good performance [24]. Then, the variables can be mapped into linguistic variables like “zero”, “negative”, and “positive” for minimal number of fuzzy memberships. In this study 5 MF function was defined: “-veHigh”, “-veMid”, “Zero”, “+veMid”, and “+veHigh”. “-veHigh” and “+veHigh” catered to cover up error value if pH value reference change from 3 to 8 or vice versa. While “-veMid” and “+veMid” is for converting error value in smallscale. Then, “Zero” indicating that the error is zero and the FL controller has achieved the control objectives. For the “ de/dt ” variables, similar type of MF was used, and it can be mapped into “increased”, “noChange” and “decrease”. In which, indicating that the rate can be either increase, no change or decrease, respectively.

Lastly for the output variables, Gaussian shape is chosen because it inherits nonlinear behavior compared to triangular shape. The nonlinearity can provide smooth transition response to control valve [24]. Then, total of 5 MF function was defined: “fullClosed”, “littleOpen”, “halfOpen”, “largeOpen” and “fullOpen. This is because flow rate value between each MF has almost no significant difference. Since the final control element is control valve and it ranges from 0 to 10 millivolt crisp input value, the interval of 2 millivolt is significant opening different for flow rate to take action. On the other hand, 2.1 millivolt has no significant change in flow rate compared to 4 millivolt. The details for variables parameter and values are given in Table 6-8, which referred from [12].

Table 6. MF variables parameter and values for Input 1

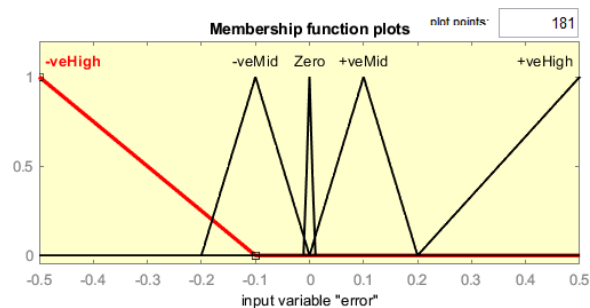
Variables		“error”		
Type	Triangular			
Range	Min: -0.5; Max: 0.5			
No	Label	a	b	c
1	-veHigh	-0.8	-0.5	-0.10
2	-veMid	-0.2	-0.1	0.00
3	Zero	-0.01	0.0	0.01
4	+veMid	0.0	0.1	0.20
5	+veHigh	0.2	0.5	0.80

Table 7. MF variables parameter and values for Input 2

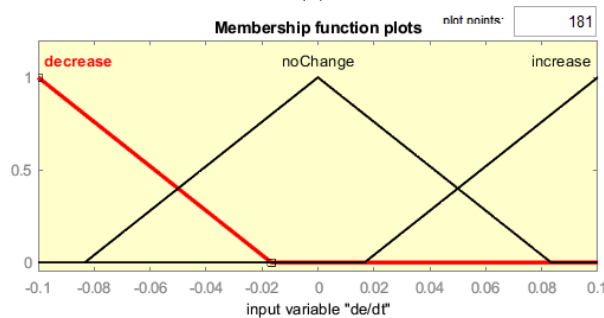
Variables		“de/dt”		
Type	Triangular			
Range	Min: -0.1; Max: 0.1			
No	Label	a	b	c
1	increase	-0.18	-0.1	-0.02
2	noChange	-0.08	0.0	0.08
3	decrease	0.02	0.1	0.18

Table 8. MF variables parameter and values for Output

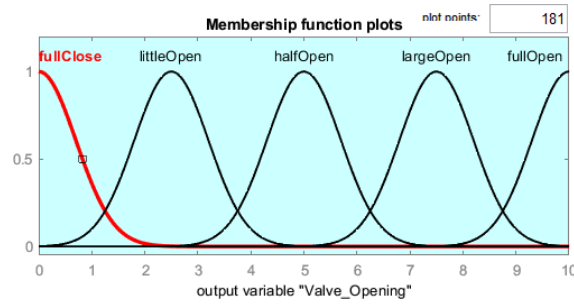
Variables		“Valve_Opening”		
Type	Gaussian			
Range	Min: 0; Max: 10			
No	Label	sigma	Gauss	
1	fullClose	0.7	0	
2	littleOpen	0.7	2.5	
3	halfOpen	0.7	5.0	
4	largeOpen	0.7	7.5	
5	fullOpen	0.7	10	



(a)



(b)



(c)
 Figure 10 Membership Functions; (a) input variable “error”
 (b) input variable “de/dt” (c) output variable “Valve_Opening”

Final step is to construct control command rules based on input and output MF defined earlier. The list of the Fuzzy rules for Mamdani’s inference system are given below:

- RULE 3: IF “error” is +veHigh AND “de/dt” is increase THEN “Valve_Opening” is fullOpen
- RULE 4: IF “error” is -veHigh AND “de/dt” is decrease THEN “Valve_Opening” is fullClose
- RULE 5: IF “error” is zero AND “de/dt” is decrease THEN “Valve_Opening” is halfOpen
- RULE 6: IF “error” is +veHigh AND “de/dt” is decrease THEN “Valve_Opening” is fullOpen
- RULE 7: IF “error” is -veHigh AND “de/dt” is noChange THEN “Valve_Opening” is fullClose
- RULE 8: IF “error” is zero AND “de/dt” is noChange THEN “Valve_Opening” is halfOpen
- RULE 9: IF “error” is +veHigh AND “de/dt” is noChange THEN “Valve_Opening” is fullOpen

In this rules, Rule 8 is the most important rule since it guaranties the Fuzzy Logic controller to meet the desired control objectives. The rest of the rules is to drive the PV to the desired SP. It involved two conditions, which is when process variable is below SP (error is positive) and above SP (error is negative). When error is positive, the system requires more base solution, so the action is to increase the opening valve. On the other hand, when error is negative, pH value in system increased, hence the valve opening must be reduced to adjust the pH to set point.

Figure 11 and 12 shows the Rules and Surfaces Viewer for the designed FL control. The Rule Viewer displays a roadmap of the whole fuzzy inference process. Basically, it shows how the variables used in the rules and gives the defuzzified output values correspond to the input [16]. For instance, when “error” is 0 and “de/dt” is 0, then the valve input signal 5 millivolt. As for the Surface Viewer, it displays a plot of output surface of the system versus any inputs to the system [16].

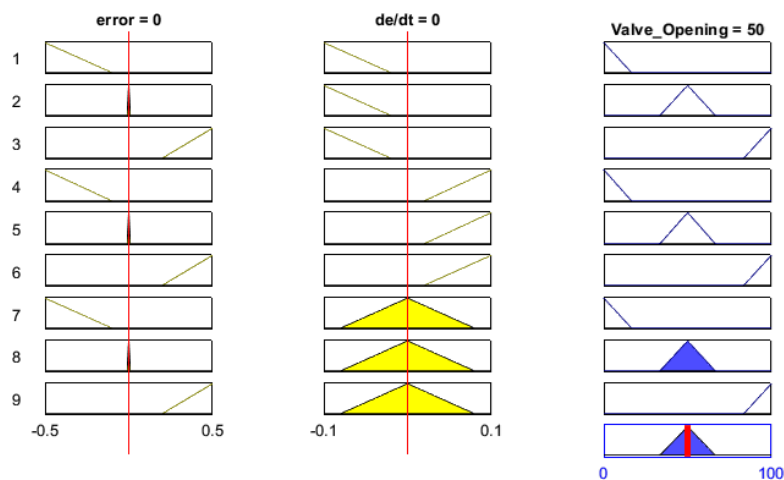


Figure 11. Window Viewer for “Rules”

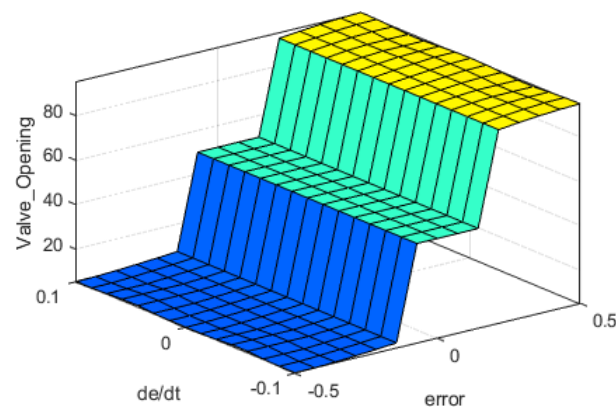


Figure 12. Window Viewer for “Surfaces”

3.4. Performance of PID Controller and Fuzzy Logic Controller

The performance for both controllers were simulated using step function in MATLAB (2021a) Simulink software. Figure 16 and 17 shows the response for pH and temperature control using PID and FL controller, respectively. In most cases, the performances are compared based on the overshoot value, settling time, peak time and rise time. In most cases, process control design goal is to minimize overshoot, as well as decreasing rise time.

For the pH control system (Figure 13), both responses show different trends. The response time for FL controller (red line) has no overshoot and quicker settling time as compared to response from PID controller (blue line). This mean that it takes shorter time for FL controller to achieve steady state condition and stable at desired set point value [4]. Both has a rather high-rise time; however, it is slightly shorter in the case of FL controller. PID response has high overshoot. Overshoot is referred to the transient values that exceeds its steady state of final value (Engineering ToolBox). Usually, a small amount of overshoot is acceptable, however, high amount of overshoot may affect greatly on the process [6].

For the temperature control system (Figure 14), both responses show similar trends. However, the settling time for FL controller (red line) is shorter as compared to PID controller (blue line). While FL controller did not have overshoot, the PID have slight overshoot but is still acceptable for the process. Measurement of MSE/ ISE/ ITAE for both pH and temperature response was not conducted in this study as this unit operation is still in the initial procedure for designing advanced process control.

Based on the responses, it shows that FL controller gives better performance, since it has the ability to reach desired set point and achieve steady state at much shorter time. In term of safety, FL controller will provide higher safety assurance as compared to PID due to the absent of overshooting. As mentioned before, overshooting may have great effect on the process. In some application, overshoot may not be a problem, for instance in control flowmeter as explained by [25]. Where the valve is the final control element. Assuming everything is sized appropriately, the valve should be able to accommodate the desired flow easily, so it may not be a big deal if it goes a little above or below the set point because it can easily reverse its efforts. However, in the case of temperature control that manipulate the amount of gas to a burner, it might rise safety issues. Say, when the system is too cold, the controller will increase the amount of gas, in order to quickly restore the process temperature. Unfortunately, if the controller overshoots the set point, it won't be able to make the liquid cooler. If there is no reverse effort available, such as cooling water, this may lead to overheating of the equipment. In this case there may not be any other counter control except for turning the burner off.

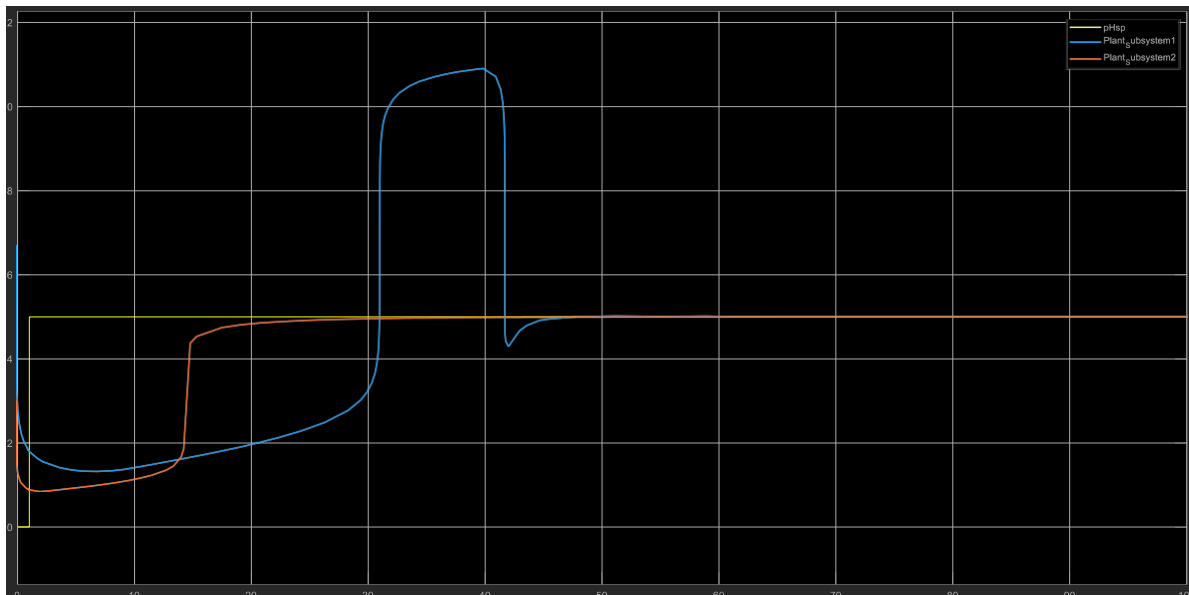


Figure 13. Response for PID and FL controller for pH control

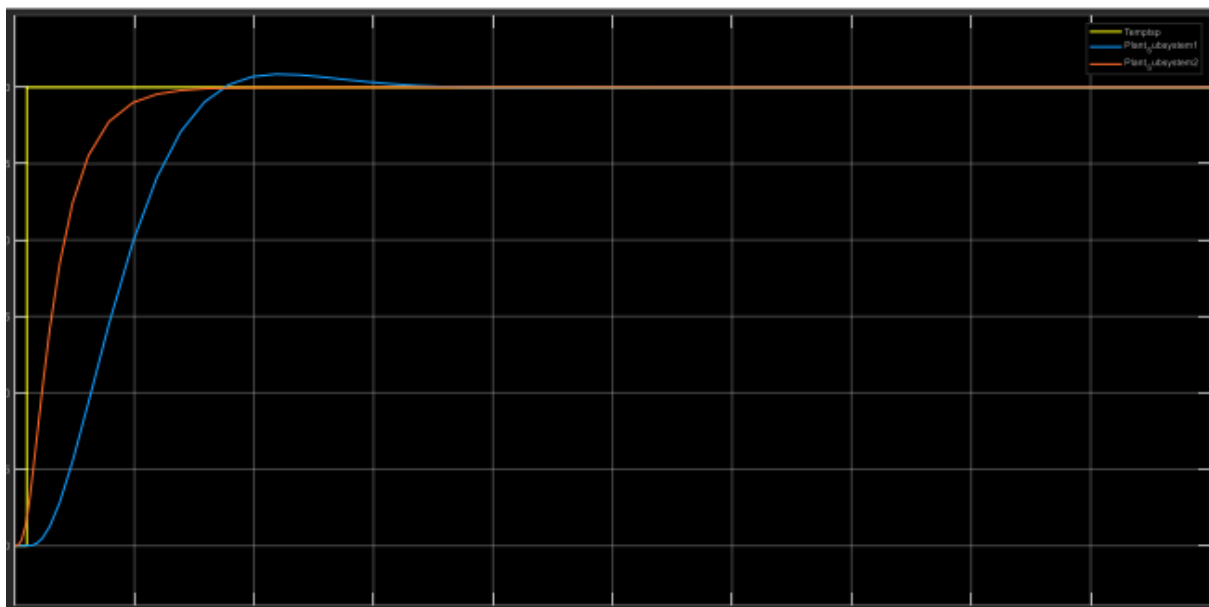


Figure 14. Response for PID and FL controller for Temperature control

4. Conclusions

Control system was design to control temperature and pH on fermenter for production of amyolytic enzymes. Two types of controllers are used and compared for the system. PID controller shows present of overshoot and longer rise and settling time. While result shows no overshoot and shorter rise and settling time. In term of safety, FL controller is much safer since it does not deal with overshooting.

PID is advantages in term as it is easy to implement but has limitation when dealing with complex and non-linear system due to parameter setting. On the other hand, FL controller integrate AI which mimic human thinking, which is prone to higher tolerance. Thus, making it suitable for non- linear system. Nevertheless, this study is a preliminary study with require further study such as a suitable tuning method for PID and TL, or use of hybrid controller system.

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References

1. Mehta, D. & Satyanarayana, T. 2016. Bacterial and archaeal α -amylases: Diversity and amelioration of the desirable characteristics for industrial applications. *Frontiers in Microbiology* 7(JUL): 1–21.
2. Singh, G. 2019. Design and Performance Analysis of PID Controller for Automatic Generation Control of an Autonomous Power System (July).
3. Putrus, K.M. & Zihwar, Z.F. 2010. Adaptive Control Of A pH Process. *Chemical Engineering Department/University of Technology* 16. http://www.uotechnology.edu.iq/dep-chem-eng/PAPERS/karema_x.pdf.
4. Merriam-webster.com. 2020. artificial intelligence [https://www.merriam-webster.com/dictionary/artificial intelligence](https://www.merriam-webster.com/dictionary/artificial%20intelligence).
5. Azman, D.N. & Hamzah, F. 2019. Production of Amylolytic Enzymes From Ragitapai (Effect of Moisture Content) (July): 8–13.
6. Izyan, N.S., Azman, D.N., Saad, N.A.M., Sauid, S. & Hamzah, F. 2020. Effect of Tacca starch loading on production of amylolytic enzymes from Ragi Tapai. *Materials Science Forum* 987 MSF: 118–123.
7. Nguyen, Q.D., Rezessy-Szabó, J.M., Claeysens, M., Stals, I. & Hoschke, Á. 2002. Purification and characterisation of amylolytic enzymes from thermophilic fungus *Thermomyces lanuginosus* strain ATCC 34626. *Enzyme and Microbial Technology* 31(3): 345–352. <http://www.sciencedirect.com/science/article/pii/S014102290200128X>.
8. Singh, P., Bhanot, S., Mohanta, H.K., Kansal, A. & Mahata, S. 2011. Fuzzy Logic based pH Control of a Neutralization Proces. *8th Control Instrumentation and System Conference (CISCON-11)* (November).
9. Kasim, N. & Rahman, N.A.B.D. 2016. Design and Production Control of Biocellulose from *Acetobacter xylinum* ,9 (June).
10. Mamat, N.H., Bahari, S., Noor, M., Ramar, L.A.L., Soh, A.C., Taip, F.S., Hazri, A. & Rashid, A. 2020. Artificial neural network model and fuzzy logic control of dissolved oxygen in a bioreactor 17(3): 1289–1297.
11. Harold Beck.2022. Process Control <https://www.haroldbeck.com/process-control/>.
12. Mohd Fauzi, Z. 2012. Neuro-Fuzzy Based Hybrid Method For Modeling And Control Of pH Neutralization 32.
13. Hahn, J. & Edgar, T.F. 2003. Process Control Systems. Dlm. Meyers, R.A. (pnyt). *Encyclopedia of Physical Science and Technology (Third Edition)* Third Edition., hlm. 111–126. New York: Academic Press. <https://www.sciencedirect.com/science/article/pii/B0122274105006128>.
14. Electrical4U. 2020. PID Controllers and PID Control in Control Systems <https://www.electrical4u.com/pid-control/>.
15. Rajabi, M., Bohloli, B. & Gholampour, E. 2010. Intelligent approaches for prediction of compressional , shear and Stoneley wave velocities from conventional well log data : case study from the Sarvak carbonate reservoir in the Abadan Plain (Southwestern Iran). *Computers and Geosciences* 36(5): 647–664. <http://dx.doi.org/10.1016/j.cageo.2009.09.008>.
16. Ariss, J. & Rabat, S. 2019. A comparison between a traditional PID controller and an Artificial Neural Network controller in manipulating a robotic arm.
17. Arun, U.P., George, S. & Mobeen, S.A. 2015. Control of pH Neutralization Process using Fuzzy Logic : A Review. *International Research Journal of Engineering and Technology* 2(3): 1081–1084.
18. Bajpai, P. 2018. Chapter 24 - Process Control. Dlm. Bajpai, P.B.T.-B.H. of P. and P. (Third E. (pnyt).hlm. 483–492.Elsevier.<https://www.sciencedirect.com/science/article/pii/B9780128142387000246>.
19. Butler, J. & LaVelle, matthew J. 2009. Degrees of Freedom - importance, calculation procedure, and exaples[https://eng.libretexts.org/Bookshelves/Industrial_and_Systems_Engineering/Book%3A_Chemical_Process_Dynamics_and_Controls_\(Woolf\)/02%3A_Modeling_Basics/2.02%3A_Degrees_of_Freedom_importance%2C_calculation_procedure%2C_and_examples](https://eng.libretexts.org/Bookshelves/Industrial_and_Systems_Engineering/Book%3A_Chemical_Process_Dynamics_and_Controls_(Woolf)/02%3A_Modeling_Basics/2.02%3A_Degrees_of_Freedom_importance%2C_calculation_procedure%2C_and_examples).
20. Cadence. 2020. What is the Significance of Signal Overshoot and How is it Reduced? <https://resources.pcb.cadence.com/blog/2020-what-is-the-significance-of-signal-overshoot-and-how-is-it-reduced>.
21. Chopra, S., Mitra, R. & Kumar, V. 2005. Fuzzy controller: Choosing an appropriate and smallest rule set 3
22. Devaraj, D. & Radhakrishnan, T.K. 2011. Swarm intelligence based system identification and

- controller tuning K . Valarmathi * and J . Kanmani (December 2016).
23. Mathworks, C. 2019. Fuzzy Logic Toolbox™ User ' s Guide R 2019 a.
 24. Electrical4U. 2020. PID Controllers and PID Control in Control Systems <https://www.electrical4u.com/pid-control/>.
 25. Martina, J.D.I. & Rammohan, T. 2014. Fuzzy Logic based PID Controller for pH Neutralization Process. International Journal of Computer Applications 95(6): 36–40.
 26. Olakusehin, V.O. & Oyedeji, O. 2021. Production of α -amylase from *Aspergillus flavus* S2-OY using solid substrate fermentation of potato (*Solanum tuberosum* L .) peel Production of α -amylase from *Aspergillus flavus* S2-OY using solid substrate fermentation of potato (*Solanum tuberosum* L .) peel (November)
 27. Devaraj, D. & Radhakrishnan, T.K. 2011. Swarm intelligence based system identification and controller tuning K . Valarmathi * and J . Kanmani (December 2016).
 28. Ong, L.H. 2015. Production, Partial Purification and Characterization of Amylase From *Sphingomonas* Sp . Isolated From Artic Soil Universiti Teknologi Malaysia. Rajabi, M., Bohloli, B. & Gholampour, E. 2010. Intelligent approaches for prediction of compressional , shear and Stoneley wave velocities from conventional well log data : A case study from the Sarvak carbonate reservoir in the ... Computers & Geosciences Intelligent approaches for prediction of compressional , shear and Stoneley wave velocities from conventional well log data : A case study from the Sarvak carbonate reservoir in the Abadan Plain (Southwestern Iran). Computers and Geosciences 36(5): 647– 664. <http://dx.doi.org/10.1016/j.cageo.2009.09.008>.
 29. Rondán-Sanabria, G.G., Valcarcel-Yamani, B. & Finardi-Filho, F. 2012. Effects on starch and amyolytic enzymes during *Lepidium meyenii* Walpers root storage. Food Chemistr 134(3)1461–1467. <http://www.sciencedirect.com/science/article/pii/S0308814612005225>.
 30. Souza, P.M. de. 2010. Application of Microbial Amylase in Industry. Brazillian Journal of Microbiology 41: 850–861.