Temperature and pH Control of Dark Fermentation Bioreactor to Produce Biohydrogen from Palm Oil Mill Effluent by Using Fuzzy Logic Controller

Ikhmal Zariq Al Imran Jamal Ikhsan[a], Norliza Abd Rahman[a], Jarinah Mohd Ali[a]

[a]Chemical Engineering Programme, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Malaysia

*Corresponding author: norlizajkkp@ukm.edu.my

ABSTRACT

Hydrogen is the main choice of renewable fuel since it brings significant benefits compared with the other conventional fuels, such as the use of waste substrate, cleaner and highest energy density. Biological hydrogen production route is cost efficient since it can be processed in ambient conditions, easy operational techniques while keeping the environment safe. Dark fermentation to produce bio-hydrogen has received widespread attention from researchers in the present decades especially due to not requires light sources. This work is a study of the optimization of process conditions particularly pH and temperature of a dark fermentation bioreactor to produce Bio-H_2 from palm oil mill effluent (POME) by using fuzzy logic controller. The simulation started by developing process and instrumentation diagram (P&ID) of bioreactor. Then a conventional PID controller and fuzzy logic controller were simulated by using MATLAB SIMULINK and the results were compared with each other in terms of safety aspect. The temperature of 37^oC and pH of 6 is the optimum conditions that needs to be maintained to yield the hydrogen at 2.79 mol H_2 mol^{-1} glucose. The pH is able to reach optimum value at 600s and 30s by using the PID controller and fuzzy logic controller, respectively. Same goes to temperature control, where the parameter reaches optimum value at 200s and 0.3s respectively. Based on these promising results, fuzzy logic controller is a good replacement for the conventional control systems since it requires shorter time to optimize process conditions, consequently making sure the safety aspect is well guaranteed.

Keywords: Dark Fermentation, Bio-H_2, POME, PID Controller, Fuzzy Logic Controller

INTRODUCTION

Malaysia currently accounts for 28 percent of global palm oil production and 33 percent of global exports, making palm oil one of Malaysia's leading agricultural products (Lok et al. 2020). This can be proved where the palm oil industry contributed to 8.7% of the country's gross domestic product (GDP) in 2018 (Mahmod et al. 2020). In recent times, over 19.4 million tonnes of crude palm oil have been extracted, accounting for approximately 20% of total processed fresh fruit bunches, with the remaining 65% remaining as POME by-products (Maaroff et al. 2019). Palm oil mill effluent (POME) is produced during processing oil palm from palm oil mill for, which consists of 95% of water and 5% solids, with high chemical oxygen (COD) demand, biological oxygen demand (BOD) and acidity (Sarwani et al. 2019).

The current global energy demand is largely dependent on depleting fossil fuel reserves, and the world is facing severe pollution problems as a result of the by-products produced from usage of fossil (Ghimire et al. 2015). One of the main sources of greenhouse gas emission is combustion of fossil fuel and waste (Panin et al. 2021). Thus, hydrogen has provided hope for achieving the need for sustainable and clean alternative energy sources to reduce the dependence on fossil fuels. Hydrogen is expected to play a key role in decarbonising the energy and transport sector (Sekoai et al. 2020). Currently, more than 90% of hydrogen is generated through catalytic reforming of natural gas or fossil fuels, which emits huge amounts of CO_2 as by-product into the atmosphere (Ghosh et al. 2018). Apart from that, other routes of hydrogen or so called bio-hydrogen can be produced through different processes including photolysis, photo-fermentation, dark-fermentation, and CO gas-fermentation (Akhlaghi & Najafpour-Darzi 2020).

These biological routes are much eco-friendly and less energy demanding compared to the chemical or physico-chemical processes (Ghosh et al. 2018). The dark fermentation process seems to be more interesting since it does not require any light energy, moderate process conditions, and lower energy requirements (Gopalakrishnan et al. 2019). Back to topic, the discharge of untreated POME can be harmful to the environment as it is has an unpleasant smell with other dissolved organic materials that can contaminate water bodies (Hamzah et al. 2020). The high nutrient content in the POME allows it to be an ideal source of sugar feedstock and possibly to be utilized as fermentation medium in anaerobic treatment processes

(Jamali & Jahim 2016). The requirement for POME to be released to the water stream should meet the regulatory standard of BOD (20 mg/L), COD (1000 mg/L), total solid (1500 mg/L), suspended solid (400 mg/L), oil and grease (50 mg/L) and total nitrogen (50 mg/L)(Syafiqah Hazman et al. 2018). Thus, the utilisation of POME into bio-hydrogen can help to boost up the hydrogen economy and reduce the impact of the effluent into the environment by treating it and lowered the pollutant concentration.

When it comes to using feedback control, the PID controller has long been a go-to choice. It can be used in a variety of technical fields, including industrial processes and process instrumentation (Khew Mun Hong et al. 2021). Several scholars have paid attention to the fuzzy logic method, which has been used in a variety of areas, including ecosystems and environmental science, as well as energy evaluation and prediction of anaerobic digestion processes (Cárdenas et al. 2020). FLC has the ability to process input data while also producing the required output by executing rules (Sulaiman et al. 2018; Suspensions 2001).

In this study, an optimisation of process conditions of a bioreactor has been done to produce of Bio-H$_2$ from dark fermentation of POME. The objective of this study began with construction of piping and instrumentation diagram of bioreactor, followed by simulation of conventional PID control system and Fuzzy Logic control systems, and comparison between the response of both controllers in terms of safety aspect.

<div align="center">METHODOLOGY</div>

CONSTRUCTION OF PIPING AND INSTRUMENTATION DIAGRAM (P&ID)

To develop a process control system, constructing a piping and instrumentation diagram (P&ID) is a crucial step since it allows to see the functional relationship between pipeline, instrumentation, and system equipment components (Ray et al. 2020). Hence, flow diagram is the most effective method to deliver information about a process (Turton et al. 2018). So, P&ID will be developed after a thorough literature review on production of Bio-H$_2$ from POME. The operating conditions, the reaction stoichiometry, are the main data that needs to be determined in this study.

SIMULATION OF CONVENTIONAL PID CONTROL SYSTEM

A wide known of conventional process control system is proportional (P), integral (I), derivative (D), proportional-plus-integral (PI), proportional-plus-integral-plus-derivative (PID). When choosing a controller, one must make sure it has a fast respond, minimum overshoot, and low steady state error for a particular process unit (Kumar 2014). The steps

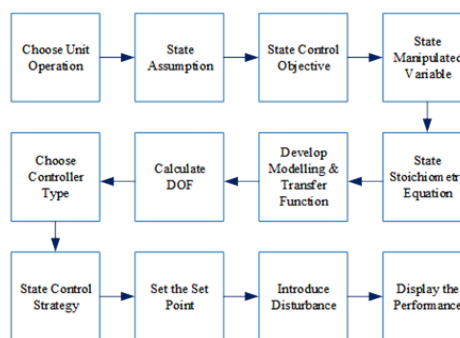to simulate the conventional controller of unit operation has been shown in Figure 1 below.

FIGURE 1. Steps in Conventional Process Control System

First step, bioreactor is chosen as the unit operation while PID controller as the conventional controller. Next, Figure 2 represents the extension of steps in Figure 1 that can be followed to construct the conventional controller by using MATLAB SIMULINK R2021b software. By using the software, a block diagram of process control system will be done with and without conventional PID controller to compare the output response. After the simulation finished, the study will be proceeded with the simulation of fuzzy logic controller.
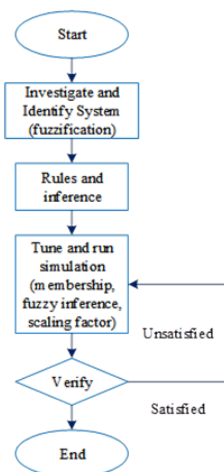

FIGURE 2. Steps in Simulation of Conventional Process Control System
Source: Zohedi et al. 2020

SIMULATION OF FUZZY LOGIC CONTROLLER (FLC) SYSTEM

Figure 3 represented the steps that needs to be followed by using MATLAB SIMULINK R2021b software to construct FLC system.
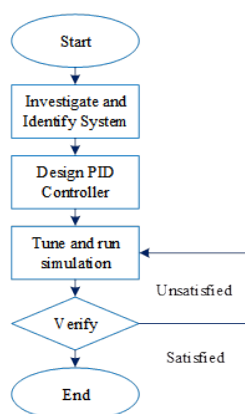
FIGURE 3. Steps in simulation of FLC Control System

Table 1 shows the settings on the Fuzzy Logic Designer Toolbox for developing rules and surface viewer.

TABLE 1. Fuzzy Logic Designer Toolbox Settings

Input Variable(s)	pH and Temperature
Output Variable(s)	Yield of bio-H_2
Inference System	Mamdani
Membership function	Triangular representation
Defuzzification	Centroid

RESULTS AND DISCUSSION

PIPING AND INSTRUMENTATION DIAGRAM (P&ID)

After enough data has been collected on production of POME to Bio-H_2, the P&ID of bioreactor is constructed as shown in Figure 4 while Table 2 shows the description of each symbol in the P&ID.

TABLE 2. Symbols Description in PFD

Symbols	Description
◐	Input & Output
◇	Stream Number
▭	Utility

Before entering the bioreactor, POME sludge taken from anaerobic pond at 9d sludge age are collected at Tennamaram Palm Oil Mill, Bestari Jaya, Selangor and pre-heated at 80ºC to inactivate hydrogenotrophic methanogens and enrich it for the HPB before cooling down to 25ºC (Akhbari et al. 2019; Mahmod et al. 2021). Substrate (POME) also collected at the same pond, after acidification process and cool down to 4ºC. Then, POME substrate at 4ºC together with pre-treated POME sludge at 25ºC enters the bioreactor

(FR-101) and were stirred at 150 rpm to cultivate the hydrogen mixed bacteria. Then, the bioreactor was sparged with nitrogen (N_2) gas for 3 minutes to allows operations in anaerobic conditions. The pH was adjusted with sodium hydroxide (NaOH) and hydrochloric acid (HCL) (Akhbari et al. (2019), while the bio-reactor temperature is controlled by circulating a jacket around the bio-reactor with hot water (Lutpi et al. 2016).
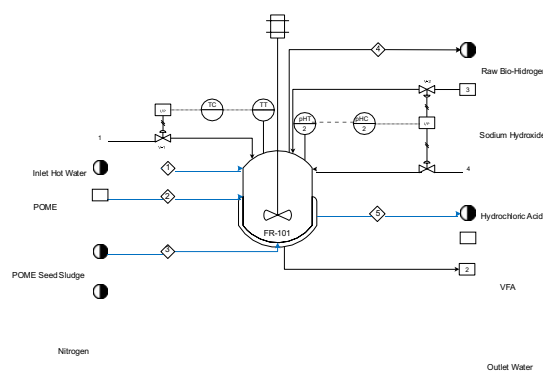

FIGURE 4. P&ID of Bioreactor (FR-101)

As can be seen in the P&ID from Figure 4, two feedback controller was done on the bioreactor which is for pH and temperature. As can be seen, a transmitter denoted by (TT) and (pHT) will detect any deviations from the set point, and then controller denoted by (TC) and (pHC) will adjust the input variable until it achieved to desired set point value. Controllers' decision will determine whether the control valve is opened or closed.

CONVENTIONAL PID CONTROL SYSTEM

This section discussed the result of simulation conventional control system on bioreactor. The explanation will be done one by one as referred to the steps given in the methodology section. Since bioreactor has been chosen, the assumption for this unit operation is constant volume, perfectly mixed, steady-state process, and jacket for controlling the operating temperature.

The control objectives are to control pH and temperature of the bioreactor. Thus, the variables need to be manipulated is the amount of sodium hydroxide (NaOH) and hydrochloric acid (HCL) and amount of hot water circulating the jacket of bioreactor. Next step is to determine the stoichiometry of the dark fermentation of POME. Based on paper by Sivaramakrishnan et al. (2021), eq. (1) below represents the stoichiemetry equations for dark fermentation of POME to Bio-H_2.

$$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 4H_2 + 2CO_2 \qquad (1)$$

To develop the transfer function, mass and energy balance were develop as shown in Equation (2) to (7).

Total Mass Balance,

$$\rho \frac{dV}{dt} = \rho_1 F_1 + \rho_1 F_2 - \rho_3 F_3 \tag{2}$$

Component balance on Glucose (A),

$$V \frac{dC_A}{dt} = F_1\left(C_{A,o} - C_A\right) - r_A \tag{3}$$

Component balance on Water (B),

$$V \frac{dC_B}{dt} = F_1\left(C_{B,o} - C_B\right) - r_A \tag{4}$$

Component balance on Product (C),

$$V \frac{dC_C}{dt} = F_3\left(C_{C,o} - 0\right) + r_A \tag{5}$$

Energy Balance,

$$\rho C_P V \frac{DT}{dt} = \rho C_P F_j (T_O - T) + \lambda V r_A - U_{A_H}\left(T - T_j\right) \tag{6}$$

Energy Balance on Cooling Jacket,

$$\rho j C_{Pj} V j \frac{DTj}{dt} = \rho j C_{Pj} F_j (Tj_O - Tj) + U_{A_H}\left(T - T_j\right) \tag{7}$$

Derive the equation, to obtain the transfer function for pH and the temperature as shown in Eq. (8) and (9).

$$TF_{Temperature} = \frac{T'(S)}{Tj'(S)} = \frac{5.111}{0.0637s + 1} \tag{8}$$

$$TF_{pH} = \frac{0.8281}{5s + 1} \tag{9}$$

Next, there 10 number of variables, with 6 equations and 2 disturbances, so the degree of freedom (DOF) was calculated as shown below.

$$\text{Degree of Freedom} = 10\,(V) - 6\,(Eq.) - 2\,(D) = 2$$

Based on the DOF, it can be confirmed that there were two controllers requires to control pH and temperature. The set point is set to 37°C and pH of 6. The fermentation takes 24 hours, and innoculum substrate ratio (ISR) at 0.8. The disturbance is the temperature and pH inlet of the bioreactor. Figure 5 shows the Simulink block, where the simulation is done with and without PID controller.
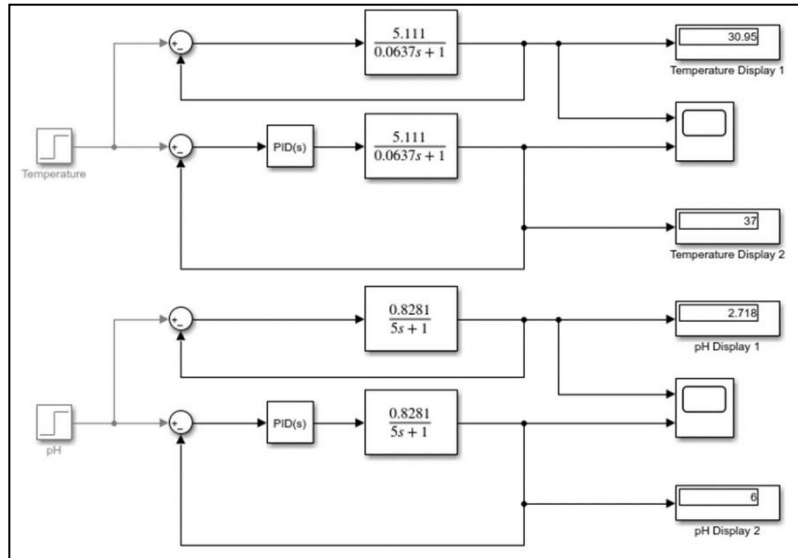

FIGURE 5. Simulink Block (With and Without PID Controller)

Table 3 shows the data obtained from Akhbari et al. (2019) which was applied to develop the FLC rules.

TABLE 3. Data of pH, Temperature and Yield of Bio-H$_2$

Input		Output
pH	Temperature (°C)	Hydrogen Yield (mol H$_2$ mol^{-1} glucose)
6.00 (H)	30.00 (L)	3.26 (H)
5.50 (M)	35.00 (M)	3.32 (H)
5.00 (L)	30.00 (L)	1.01 (L)
5.50 (M)	35.00 (M)	2.63 (M)
5.00 (L)	40.00 (H)	2.63 (M)
5.50 (M)	35.00 (M)	2.69 (M)
5.0 (L)	40.00 (H)	3.46 (H)
6.00 (H)	40.00 (H)	3.42 (H)
5.50 (M)	35.00 (M)	2.7 (M)
6.00 (H)	40.00 (H)	3.63 (H)
5.50 (M)	30.00 (L)	3.29 (H)
6.00 (H)	35.00 (M)	3.82 (H)

Source: (Akhbari et al. 2019)

Next, Figure 6 and Figure 7 shows the main view and membership function in Fuzzy Logic Designer Toolbox.
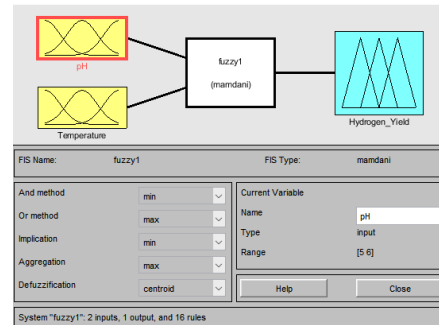

FIGURE 6. Main View of Fuzzy Logic Designer

Based on the parameter in Table 3, the membership function was developed by inserting the lowest value and highest value for each input and output as shown in Figure 7.
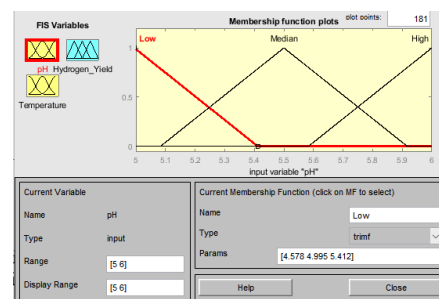

FIGURE 7. Membership Function Plot

Then, as shown in Figure 8, once the rules have been set-up, we can see the 3D XYZ relationship between the input variables which is pH and temperature towards the output of the process which is the yield of Bio-H$_2$. At 37°C and pH of 6, the yield of Bio-H$_2$ is 2.79 mol H$_2$ mol^{-1} glucose.
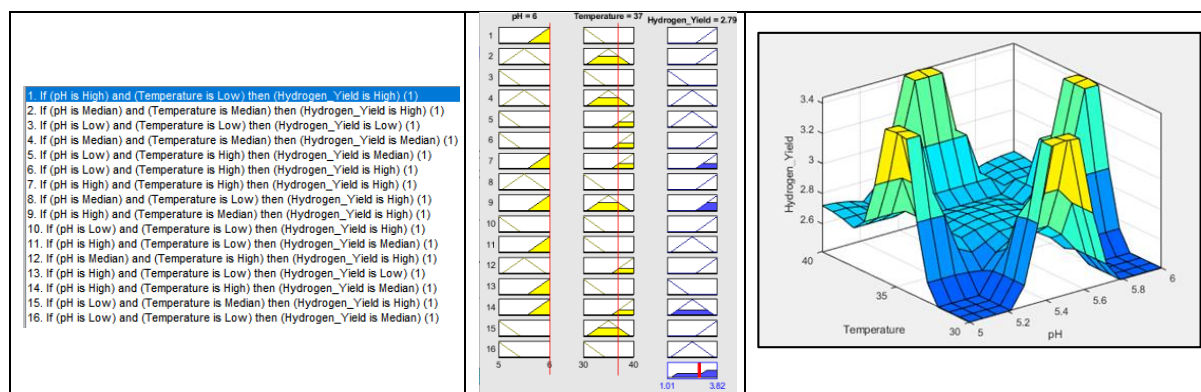

FIGURE 8. Rules, Rules Viewer and Surface Viewer on FLC

SIMULATION OF FUZZY LOGIC CONTROLLER (FLC) SYSTEM

Once creating the rules and surface viewer in the Fuzzy Logic Designer Toolbox in MATLAB has been done, now .fis data files will be exported into the workplace of SIMULINK, to begin incorporating fuzzy logic technique for process control system. This simulation were done by following all the steps mentioned in Methodology section earlier. Figure 9 shows the Simulink block of fuzzy logic control for pH and temperature, respectively for the bioreactor developed by using MATLAB SIMULINK R2021b.

After both conventional PID control system and FLC system has been developed, now the comparison of response between the two controllers can be done.
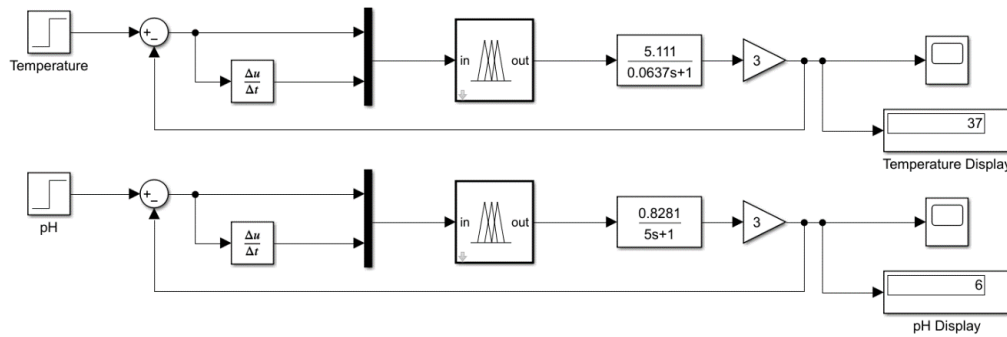

FIGURE 9. Simulink Block of FLC

After both conventional PID control system and FLC system has been developed, now the comparison of response between the two can be done. Figure 10 shows the output response of pH in bioreactor without the controller, with PID controller, and FLC. Without any controller, the pH cannot reach to desired value of 6, and it only able to be maintained pH at 2.8. But, when PID and FLC controller was used, it able to reach the desired value at 600s and 30s respectively.

Same goes to temperature parameter, without controller, it seems that the bio-reactor is unable to maintain its temperature to desired value of 37°C. By using PID controller, it can maintain the temperature at 37°C after 200s while FLC shows a very fast response, which is only takes 0.3s to maintain the temperature at 37°C.
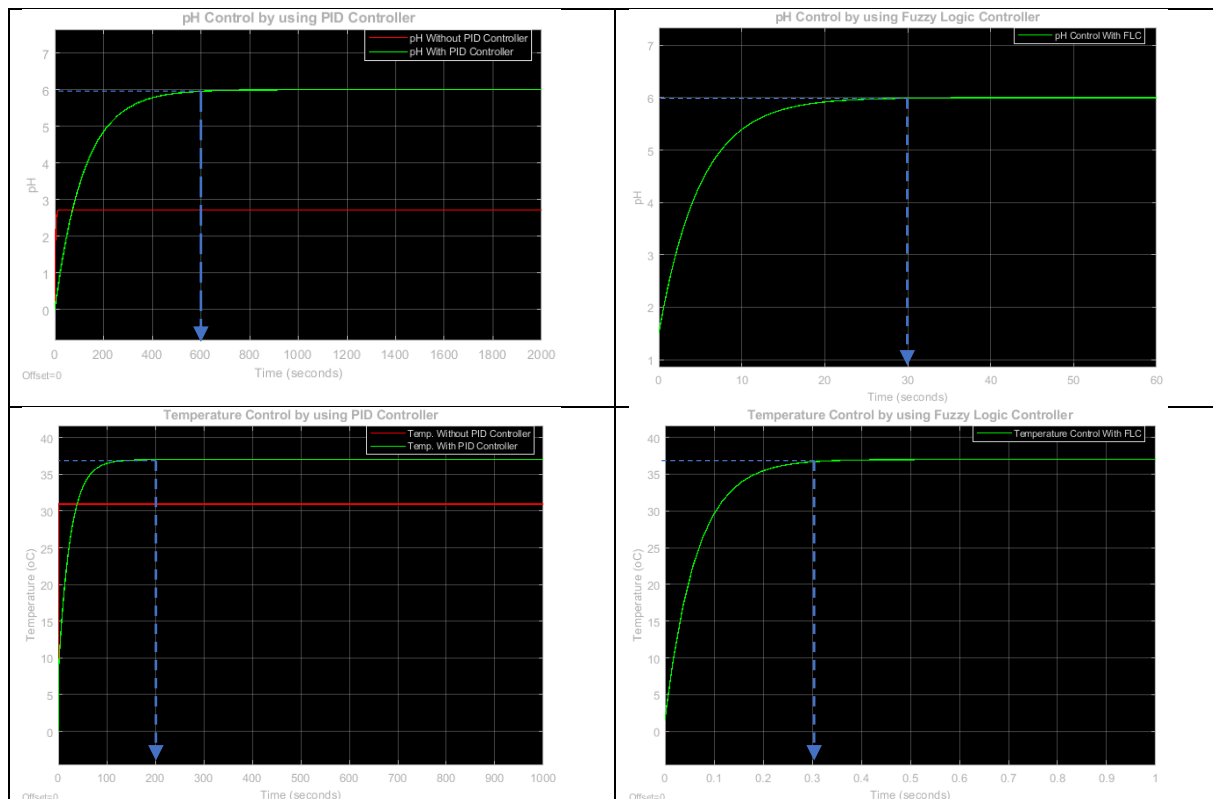

FIGURE 10. pH and Temperature Output Response in Bioreactor (Without PID, PID, & FLC)

Based on these results, FLC can provide more effective production of Bio-H$_2$ from POME in bioreactor compared to the conventional controller. This can be proved by Pratiwi et al. (2015), where the temperature control in dark fermentation bioreaction able the maintain substrate temperature at fluctuation and mean error of 0.06 and 0.117^{o}C.

EFFECT OF CONTROLLERS ON PROCESS SAFETY ASPECT

The choice of process controller is very important. PID controller can be efficient in linear systems, but FLC is at another level since it both suited for linear and non-linear systems (Ivanova et al. 2016). Fuzzy logic provides fast response times with virtually no overshoot. Loops with noisy process signals have better stability and tighter control when fuzzy logic control is applied (Al-odienat & Al-lawama 2008).

Manufacturing processes are dangerous especially chemical and petrochemical sectors. The use of controller whether conventional PID or the advanced one (FLC) can helps to maintain the desired set point of a process, so it will help to prevent any deviations of process parameter that can leads to a hazard situation. For example, if the temperature controller cannot well maintain the temperature, the bioreactor may overheat and may cause dangers to the surrounding if not being careful. In terms of pH, NaOH and HCL is added into the reactor to control the pH in the bioreactor. If there are no controllers, the pH in bioreactor might become too acidic. If there is a leaking on bioreactor, it will bring dangers to the people at the area. That are the reasons why controllers are needed, and the best controllers must be well chosen for a particular processing unit.

CONCLUSION

This purpose of this work is to demonstrate a novel application of FLC on dark fermentation bioreactor to produce Bio-H$_2$ from POME. In order to ensure a well-controlled condition of Bio-H$_2$ production at desired condition, simulations of with and without PID controllers and FLC on bioreactor has been done. Without the PID controller system, the output value cannot reach the optimum value at all. In addition, simulation through fuzzy logic control system (FLC) is preferable and accurate than conventional PID control system due to desirable output produced from it. Besides, a shorter time for optimization will brings benefit process safety, as it will allow for faster response to any deviation from the set point. As a conclusion, FLC is shown to have a superiority over PID controller since it is giving acceptable and stable Bio-H$_2$ production with low to zero deviation from set point. However, further study can be done to make sure the result is well validated.

REFERENCES

Akhbari, A., Zinatizadeh, A.A., Vafaeifard, M., Mohammadi, P., Zainal, B.S. & Ibrahim, S. 2019. Effect of operational variables on biological hydrogen production from palm oil mill effluent by dark fermentation using response surface methodology. *Desalination and Water Treatment 137* (September 2018): 101–113.

Akhlaghi, N. & Najafpour-Darzi, G. 2020. A comprehensive review on biological hydrogen production. *International Journal of Hydrogen Energy 45*(43): 22492–22512.

Al-odienat, A.I. & Al-lawama, A.A. 2008. The Advantages of PID Fuzzy Controllers Over The Conventional Types *5*(6): 653–658.

Cárdenas, E.L.M., Zapata-Zapata, A.D. & Kim, D. 2020. Modeling dark fermentation of coffee mucilage wastes for hydrogen production: Artificial neural network model vs. fuzzy logic model. *Energies 13*(7)

Du, Z., Liu, C., Zhai, J., Guo, X., Xiong, Y., Su, W. & He, G. 2021. A review of hydrogen purification technologies for fuel cell vehicles. *Catalysts 11*(3): 1–19.

Gandiglio, M., Lanzini, A., Santarelli, M., Acri, M., Hakala, T. & Rautanen, M. 2020. Results from an industrial size biogas-fed SOFC plant (the DEMOSOFC project). *International Journal of Hydrogen Energy 45*(8): 5449–5464.

Ghimire, A., Frunzo, L., Pirozzi, F., Trably, E., Escudie, R., Lens, P.N.L. & Esposito, G. 2015. A review on dark fermentative biohydrogen production from organic biomass: Process parameters and use of by-products. *Applied Energy 144*: 73–95.

Ghosh, S., Chowdhury, R. & Bhattacharya, P. 2018. A review on single stage integrated dark-photo fermentative biohydrogen production: Insight into salient strategies and scopes. *International Journal of Hydrogen Energy 43*(4): 2091–2107.

Gopalakrishnan, B., Khanna, N. & Das, D. 2019. *Dark-Fermentative Biohydrogen Production. Biohydrogen*

Hamzah, M.A.F., Abdul, P.M., Azahar, A.M. & Jahim, J.M. 2020. Performance of Anaerobic Digestion of Acidified Palm Oil Mill Effluent under Various Loading Rates and Temperatures. *Water 12*: 2432.

Ivanova, N., Gugleva, V., Dobreva, M., Pehlivanov, I., Stefanov, S. & Andonova, V. 2016. Safety Aspect on Fuzzy Logic Controller. *Intech i*(tourism): 13.

Jamali, N.S. & Jahim, J.M. 2016. Pengoptimuman pengeluaran biohidrogen termofilik oleh mikroflora efluen kilang minyak sawit: Lampiran sel pada karbon berbutir aktif sebagai media sokongan. *Malaysian Journal of Analytical Sciences 20*(6): 1437–1446.

Khew Mun Hong, G., Hussain, M.A. & Abdul Wahab, A.K. 2021. Fuzzy logic controller implementation on a microbial electrolysis cell for biohydrogen production and storage. *Chinese Journal of Chemical Engineering* (xxxx)

Koroglu, E.O., Ozdemir, O.K., Ozkaya, B. & Demir, A. 2019. An integrated system development including PEM fuel cell/biogas purification during acidogenic biohydrogen production from dairy wastewater. *International Journal of Hydrogen Energy 44*(32): 17297–17303.

452

Kumar, R. 2014. Comparative Study of Conventional Controllers. *International Journal of Electrical, Electronics and Data Communication 2*(10): 2320–2084.

Lok, X., Chan, Y.J. & Foo, D.C.Y. 2020. Simulation and optimisation of full-scale palm oil mill effluent (POME) treatment plant with biogas production. *Journal of Water Process Engineering 38*(March): 101558.

Lutpi, N.A., Md Jahim, J., Mumtaz, T., Harun, S. & Abdul, P.M. 2016. Batch and continuous thermophilic hydrogen fermentation of sucrose using anaerobic sludge from palm oil mill effluent via immobilisation technique. *Process Biochemistry 51*(2): 297–307.

Maaroff, R.M., Md Jahim, J., Azahar, A.M., Abdul, P.M., Masdar, M.S., Nordin, D. & Abd Nasir, M.A. 2019. Biohydrogen production from palm oil mill effluent (POME) by two stage anaerobic sequencing batch reactor (ASBR) system for better utilization of carbon sources in POME. *International Journal of Hydrogen Energy* (July): 3395–3406.

Mahmod, S.S., Azahar, A.M., Luthfi, A.A.I., Abdul, P.M., Mastar, M.S., Anuar, N., Takriff, M.S. & Jahim, J.M.D. 2020. Potential Utilisation of Dark-Fermented Palm Oil Mill Effluent in Continuous Production of Biomethane by Self-Granulated Mixed Culture. *Scientific Reports 10*(1): 1–12.

Mahmod, S.S., Jahim, J.M., Abdul, P.M., Luthfi, A.A.I. & Takriff, M.S. 2021. Techno-economic analysis of two-stage anaerobic system for biohydrogen and biomethane production from palm oil mill effluent. *Journal of Environmental Chemical Engineering 9*(4): 105679.

Panin, S., Setthapun, W., Elizabeth Sinsuw, A.A., Sintuya, H. & Chu, C.Y. 2021. Biohydrogen and biogas production from mashed and powdered vegetable residues by an enriched microflora in dark fermentation. *International Journal of Hydrogen Energy 46*(27): 14073–14082.

Pratiwi, B., Ramdlankirom, M. & Fauziiskandar, R. 2015. Design of Temperature Control Based Fuzzy Logic for Substrate in Thermophilic Hydrogen Reactor (1): 85–90.

Ray, S. & Das, G. 2020. *Process Equipment and Plant Design*. *Process Equipment and Plant Design*. Elsevier.

Sarwani, M.K.I., Fawzi, M., Osman, S.A. & Nasrin, A.B. 2019. Bio-methane from palm oil mill effluent (POME): Transportation fuel potential in Malaysia. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 63*(1): 1–11.

Sekoai, P.T., Daramola, M.O., Mogwase, B., Engelbrecht, N., Yoro, K.O., Petrus du Preez, S., Mhlongo, S., Ezeokoli, O.T., Ghimire, A., Ayeni, A.O. & Hlongwane, G.N. 2020. Revising the dark fermentative H2 research and development scenario – An overview of the recent advances and emerging technological approaches. *Biomass and Bioenergy 140*(October 2019): 105673.

Sivaramakrishnan, R., Shanmugam, S., Sekar, M., Mathimani, T., Incharoensakdi, A., Kim, S.H., Parthiban, A., Edwin Geo, V., Brindhadevi, K. & Pugazhendhi, A. 2021. Insights on biological hydrogen production routes and potential microorganisms for high hydrogen yield. *Fuel 291*(June 2020)

Sulaiman, N.N., Rahman, N.A. & Esa, F. 2018. Monitoring Production of Bacterial Cellulose by Acetobacter xylinum 0416 with Fuzzy Logic via Simulation (Pemantauan Penghasilan Selulosa Bakteria oleh Acetobacter xylinum 0416 Menggunakan Simulasi Logik Kabur). *Jurnal Kejuruteraan SI 1*(7): 21–26.

Suspensions, P. 2001. Active control of vehicle vibration 37–45.

Syafiqah Hazman, N.A., Mohd Yasin, N.H., Takriff, M.S., Hasan, H.A., Kamarudin, K.F. & Mohd Hakimi, N.I.N. 2018. Integrated palm oil mill effluent treatment and CO2 sequestration by microalgae. *Sains Malaysiana 47*(7): 1455–1464.

Turton, R., Shaeiwitz, J.A., Bhattacharyya, D. & Whiting, W.B. 2018. *Analysis, Synthesis, and Design of Chemical Processes*. Edisi ke-5. Pearson Education, Inc.

Wang, X., Baker, P., Zhang, X., Garces, H.F., Bonville, L.J., Pasaogullari, U., Molter, T.M., Song, C., Pei, P., Wang, M., Chen, D., Ren, P., Zhang, L., Hussain, S., Yangping, L., Oono, Y., Fukuda, T., Sounai, A., Hori, M., Dincer, I., Rosen, M.A., Wang, F., Deng, S., Zhang, H., Wang, J., Zhao, J., Miao, H., Yuan, J., Yan, J., Elmer, T., Worall, M., Wu, S., Riffat, S.B., Joshua O, S., Ejura G, J., Essien V, E., Olokungbemi I, B., Oluwaseun A, Y. & Okon E, P. 2020. Fuel cell technology for domestic built environment applications: State of-the-art review. *International Journal of Scientific Engineering and Research 4*(4): 2347–3878. www.nedstack.com/technology/fuel-cell-comparis.

Zohedi, F.N., Shahrieel, M., Aras, M., Kasdirin, H.A., Zhehow, L. & Bahar, M.B. 2020. Comparison analysis of the PID controller and fuzzy logic controller (FLC) for a newly developed remotely operated vehicle (ROV) depth control. *Proceedings of Mechanical Engineering Research Day* (December): 131–133.