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Fuzzy Control for Ph and Temperature in the Glucose Isomerisation Process

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ABSTRACT
Present studies describe the on-line control of some parameters such as pH and reaction temperature for the biosynthesis of fructose by Immmobilised Glucose Isomerase (IGI) of S.murinus in a bioreactor using fuzzy logic control. The process of fermentation was carried out in a 2-L batch bioreactor (New Brunswick Scientific, USA) with a working volume of 1.5 L. All of the parameters were automatically controlled with the help of attached software. The optimum pH and temperature, for the production of fructose by Immmobilised Glucose Isomerase (IGI) of S.murinus were found to be 8 and 60oC, respectively. The performance of the fuzzy logic of the bioreactor was found to be encouraging for enhanced production of the fructose with IAE and ISE less than one. The maximum production of fructose during the present study was found to be 9.26 gL-1 for batch reactor (STR).

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INTRODUCTION

Dynamic behaviour of process control relates to time-dependent behaviour of the process. In other words, the variables in the process change with time in unsteady-state condition. Open- loop response is the behaviour without controllers in the system whereas a closed - loop response is the behaviour with controllers [1-3]. The importance of controllers for glucose isomerisation processes has been shown by Haas *et al.,* [4] and Kim *et al.,* [5] who found that about 10% of an enzyme could be conserved under optimal condition in comparison with isothermal condition. According to Grubecki & Wojick [6], there is a significant indicator while choosing between isothermal and optimal temperature policy. Beside temperature, pH is another important parameter of this enzymatic isomerisation process [7]. Since the enzyme and often also the reactants and products need to be controlled in a tight window of pH, then the control of pH is critical [8] in the glucose isomerisation process.

The research conducted for glucose isomerisation by Salehi *et al*. [9] concerns the optimal design of down flow jet loop reactor with different enzyme concentration. Effect of variables such as pH, gas flow rate, enzyme inactivation and substrate concentration were not studied. Gram & Bang [10] used fixed-bed reactor with immobilized glucose isomerase at pH ranging from 6 to 9.5. The optimum temperature was at 60^{o}C. On-line flow injection analysis was used for their study which is a similar approach by Zhang *et al.,* [11]. In 1965 Professor Lotfi Zadeh introduced Fuzzy Logic [12]. It is a highly successful practical technique used to aid decision-making and control equipment. It is practical because Fuzzy Logic deals with vague, imprecise and uncertain knowledge and data. Since control aspects were not studied from previous research, therefore addition of on-line control and monitoring is the objective for this work. This study also a continuous research from Abd.Rahman *et al*. [13], which only focus for conventional control.

MATERIALS AND METHODS

The experimental works were carried out in a 2L double-jacketed stirred tank reactor with water bath. The materials used in the present study were all of analytical grade. D-glucose (G), D-fructose (F) and Magnesium Sulfate rehydrate, $MgSO_4.7H_2O$ was obtained from R&M Chemical, UK. The Immmobilised Glucose Isomerase (IGI) of *S.murinus*, was purchased from Novozymes, Denmark available in the form of brown cylindrical shape granules with diameter of 0.3 to 1.0 mm and length of 1.0 to 1.5 mm. The

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enzyme activity (as stated by the supplier) was 350 IGIU/g. The fructose and glucose concentration were determined by the High Performance Liquid Chromatography (HPLC) method using Refractive Index (RI) detector at the end of experiment (60 minutes) since the bioreactor is in batch mode [9, 14-15]. These findings [16] have shown that the detectors of UV can also measure fructose and glucose concentration using Kromasil columns. In a Closed – loop system, the experimental set-up for the presence of the heater installed to control the temperature and a dosing pump was added for adjusting pH by addition of 0.1M of NaOH. For temperature control, the usage of a heater of 21 cm in length (only 8 cm for heating zone) with diameter of 1.3 cm was implemented inside the reactor. For temperature control, the procedure is as follows, if the measured reactor temperature T_r differs from the desired temperature, T_{set}, the controller senses the error, *e, ΔT,*

$$\Delta T = T_r - T_{set} \qquad (1)$$

And the latter as the difference between the error at time, t and the previous error, *e (t-1)*, *tdiff*,

$$tdiff = e(t) - e(t-1) \qquad (2)$$

Consequently, the controller sends a signal to change the heat input in such a way as to reduce the magnitude of the error. Similar procedure was applied for pH control. The final control element is the heating element for temperature control and a variable peristaltic pump to control the pH. The basis of a fuzzy or any fuzzy rule system is the inference engine responsible for the input fuzzification, fuzzy processing and defuzzification of the output. Similar operating condition as in the conventional control was used in this fuzzy logic control. With fuzzy logic control, the pump and the heater were connected to the computer that has interfaced with the fuzzy logic control. Based on the rules set up in the fuzzy system the pump and the heater would operate accordingly.

RESULTS AND DISCUSSION

Fuzzy Logic applications have been popular in the area of control engineering as it is a valuable technology in the design of embedded machine intelligence.

Figure 1 shows the performance in the batch reactor for 60 minutes operating condition using Fuzzy Logic controller (FLC) and PID controller at 60°C. The performances of the controllers were also compared when the set point changes from 60°C to 65°C. In order to measure the robustness of the controller, the disturbance in this system is the set point changing from 60°C to 65°C.

Figure 1 illustrates the ability of Fuzzy Logic (TFLC) and PID (TPID) controllers to maintain the temperature at set point (Tsp) from the beginning of the process. From Figure 1, it is shown that both controllers reach the set point of 60°C only after 10 minutes of the reaction. After 20 minutes, both PID and Fuzzy Logic controller successfully maintain the set point. However, the PID controller slightly deviates from the set point (±0.9°C) after 25 minutes. This could be explained in terms of the difficulty of tuning of the controller values to the optimum value. The performance using Fuzzy Logic controller (TFLC) does not display any over-shoot throughout the process.

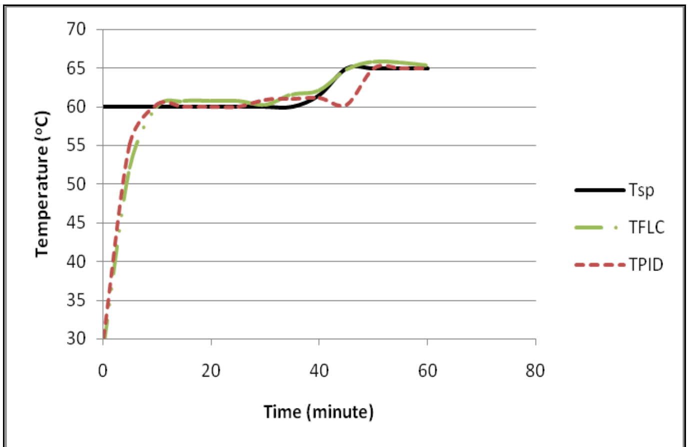

Fig. 1: Performance of Fuzzy Logic controller (pH=8, 150 rpm, Et=12 gmL^{-1}).

According to Nagrath and Gopal [17] as well as Shinskey [18], the overall performance of a control system must be in terms of certain measurable quantities such as product concentration. In this study, besides measurement of fructose concentration, 'Integral Square Error' (ISE) and 'Integral of the Absolute Error' (IAE) have been used as other performance indices. Table 1 summarizes the performance of the PID controller and FLC in terms of fructose concentration, [Fr, g/L], IAE and ISE values.

Table 1: Performance of PID controller and FLC in the Batch Reactor (Temperature)

	FLC	PID
IAE	0.016	0.023
ISE [Fr, g/L]	0.0002 9.26	0.0005 6.59

Table 1 indicates that both controllers gave values of IAE and ISE were less than one.

One of the key objectives of pH control in the batch reactor was to maintain the pH of reactor at the desired set point, (pHspt). The desired set point is at pH 8. In order to control the pH set point, the pump that was connected to the Fuzzy Logic controller (FLC) was introduced in the reactor. Figure 2 shows the performance in a batch reactor using Fuzzy Logic controller, (pHFLC) and on-off controller, (pHon-off). From Figure 2, it is observed that both On-off controller and Fuzzy Logic controller (FLC) initially maintain the pH closely to its set point within 10 minutes of the process. After 20 minutes, On-off controller overreacted to give a huge overshoot exceeding pH of 0.3 over the set point which was settled 30 minutes later. This could be explained due to the excessive amount of NaOH injected to the reactor. For On-off controller, the overshoot behaviour, though later faded the settlement, created an offset above the set point.

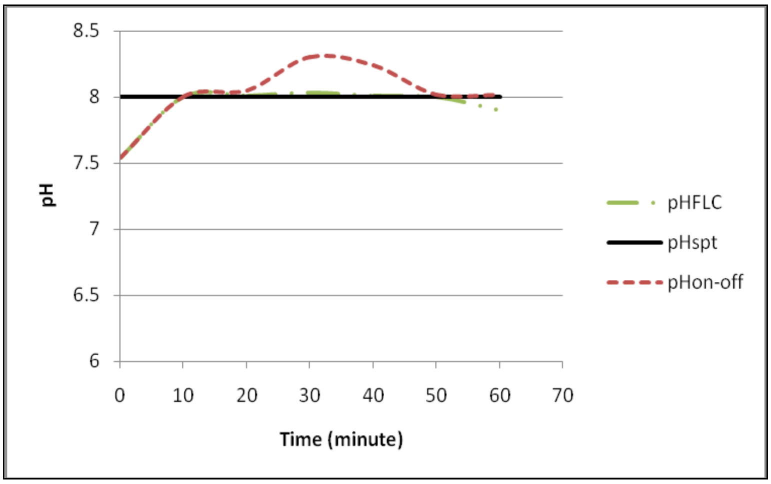

Fig. 2: Performance of pH control using Fuzzy Logic controller (T=60^{o}C, 150 rpm, Et=12 gmL^{-1}, batch reactor)

Beside the time-profile analysis, the performance of both controllers was measured by using values of fructose concentration, [Fr, g/L], IAE and ISE index (Nagrath and Gopal ,1982; Shinskey, 1988) as summarized in Table 2.

Table 2: Performance of On-Off controller and FLC in the Batch Reactor (pH)

	FLC	On-Off
IAE	0.009	0.021
ISE [Fr, g/L]	6.03E-05 9.26	0.0001 7.18

Table 2 provided the calculated values of IAE and ISE by both controllers. It shows that FLC was much better as compared to the On-off controller.

Conclusions:

The online control of temperature, the pH in the glucose isomerisation of a batch is investigated. The control objective for both temperature and pH were to obtain the optimum fructose concentration. Therefore, if the temperature and pH can be tracked very well, the target of optimum concentration can be achieved. Two controllers were tested which were ‘Fuzzy Logic Control’ and ‘Conventional Control’. The proposed advanced controller can track the set point profile very well with the excellent results of IAE and ISE (0.016 and 0.0002 for temperature controller) and (0.009 and 6.03E-05 for pH control). On the other hand, PID controller and On-off controller show poor tracking with significant oscillations and offsets.

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