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Fuzzy logic Control of Chemical Processes

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ABSTRACT

The objective of this study was to investigate the closed-loop control strategies for a batch reactor and batch distillation column using two different control methods. In this paper, fuzzy logic control has been developed and this method is compared with conventional proportional- integral-derivative controller. In the design of fuzzy controller, the knowledge obtained from the process reaction curve procedure is employed to determine proper membership functions. Fine tuning is obtained altering the output scaling factor. The forty nine rules are employed to regulate the manipulating variables to a variety of operating conditions and acquire a more flexible learning ability. The robustness of this control structure is studied in the case of setpoint changes and the fitness function for fuzzy controller is chosen as the integral of the absolute value of the error (IAE). The experimental results suggest that such fuzzy controllers can provide excellent setpoint-tracking and disturbance rejection. The results show that the fuzzy logic controller has a higher performance, in terms of robustness, response speed and the offset has a smaller average value than that of the conventional controller. According to experimental results, the fuzzy controller was considered more suitable and reliable for the batch reactor and distillation processes control with respect to the conventional controller.

Keywords: Fuzzy controller, batch reactor, batch distillation, conventional controller.

السيطرة على العمليات الكيمياوية بطريقة الدليل الغامض

الخلاصة

هدف هذا البحث تطبيق طريقتي سيطرة على المفاعل الدفعي وبرج التقطير الدفعي. في هذا البحث تم تطوير طريقة الدليل الغامض للسيطرة وتم مقارنتها بالمسيطر التناسبي-التكاملي-التفاضلي التقليدي. تم الاعتماد على معلومات تجارب الحلقة المفتوحة في إيجاد قيم دوال الانتماء حيث تم استخدام تسعة وأربعون قانون في تصميم المسيطر من اجل تنظيم متغيرات المعالجة لمدى واسع من الظروف التشغيلية ومرونة كافية لقابلية تدريب المسيطر. تم دراسة متانة الطريقة المقترحة من خلال تغيير القيمة المرغوبة وتم استخدام معيار تكامل القيمة المطلقة للخطأ لتحديد الكفاءة. أظهرت النتائج العملية إن مسيطر الدليل الغامض يعطي مسايرة ممتازة للقيمة المرغوبة وإزالة لأي اضطراب وكفاءة عالية من حيث المتانة وسرعة الاستجابة وحيد اقل من الطريقة

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التقليدية. وطبقا للنتائج العملية إن مسيطر الدليل الغامض أكثر ثقة وملائمة للعمليات التقطير والمفاعل الدفعية مقارنة بالطريقة التقليدية.

الكلمات الدالة:مسيطر الدليل الغامض, برج التقطير الدفعي,المفاعل الدفعي, المسيطر التقليدي.

Nomenclature
CE: change of error.
E: error value.
T: temperature,(^oC)
U_o: final output value of manipulating variable.
u_i: crisp values of input and output.
Val1, Val2 and Val3: Limits of the triangle membership functions.

Greek letters
$\mu(u_i)$: membership function

INTRODUCTION

Complex industrial processes such as a batch chemical reactors; batch distillation, blast furnaces and cement kilns are difficult to control automatically. This difficulty is due to their nonlinear, time varying behavior, the poor quality of models are usually complicated and difficult to solve and implement in a short sampling interval for on-line control. There are three major problems in commercial practice of chemical process control: nonlinear process behavior, constraints on operations, and ill-behaved dynamics. As a result of increasing complexity in the modern chemical processes, development of the computer-aided on-line fault diagnosis techniques has become an important issue for plant operation. Thus, the six performance criteria that a closed loop system has to satisfy are given: the closed loop system must be stable, the effects of disturbance have to be minimized, rapid and smooth responses to setpoint changes must be obtained, offset has to be eliminated, excessive control action has to be avoided, and the control system has to be robust, that is, it has to be insensitive to changes in process conditions and to errors in the assumed process model. To accomplish this performance, many kinds of strategies have been developed[1] .

Systems that have nonlinear structure cannot be exactly modeled. The interest in the design and analysis of nonlinear control system is due to several factors. Two of these factors are especially worthy of mentioning. First and foremost, linear controllers usually perform poorly when applied to nonlinear systems that operate over a wide range of operating conditions. Second, significant progress has been made in the development of model-based controller design for nonlinear systems[2]. For this reason nonlinear controllers like fuzzy controllers are used to control such systems because they are more robust than traditional controllers and can handle changes in system parameters as well[3] . The important advantage of fuzzy controllers is that a mathematical model of the system to be controlled is not required, and a satisfactory nonlinear controller can often be developed empirically without complicated mathematics. Another advantage of fuzzy logic control (FLC) is ability to control several controlled variables by less number of manipulated variables. This is extremely beneficial in processes where huge interaction between parameters exists. Fuzzy control theory enables the development of controllers derived from the valuable knowledge that a process expert accumulates over the years from empirical observations/studies with these processes[4].

Many researchers have studied the modeling of complex systems since the introduction of fuzzy logic. Fuzzy logic controllers have been widely used to control ill defined, nonlinear or imprecise systems [5] . Fuzzy control has successfully been used for controlling a number of physical systems, fuzzy logic has found a variety of applications in various fields ranging from industrial process control to medical diagnosis and to securities trading. Thus, fuzzy logic control (FLC) has become an important tool used in the construction of computational intelligence systems in chemical processes, mainly thanks to their universal function approximation property and using fuzzy logic to tune an evolutionary algorithm for dynamic optimization of chemical processes and their amenability to linguistic interpretation of the input–output relationships[6]. Fuzzy controllers have been applied successfully in wastewater treatment processes[7], risk assessment model applied in natural gas industry[8], food industry[9], design of environmental quality indexes[10] and Petroleum Processes[11]. The fuzzy logic controllers have also been applied in food and beverage processes[12], PVC polymerization process [13], tubular heat exchanger system[14], semi-batch crystallizer[15], activated sludge aeration process[16], bioreactor[17], non-isothermal continuous stirred tank reactor[18] and nuclear research reactors[19].

More and more industrial applications and commercial products of Fuzzy control are appearing every year, and typical applications already in use are process control , fluid catalytic cracking unit [20], neutralization processes[21], aeration in a submerged biofilm wastewater treatment[22] and drying process[23]. In recent years, the fuzzy control algorithm have also been applied successfully for reactors and distillation[24] by many researchers such as temperature control of a methyl methacrylate batch polymerization reactor[25], control the temperature of a styrene polymerization jacketed batch reactor in which takes place under isothermal conditions[26], control of a highly nonlinear exothermic continuous stirred tank reactor[27], continuous stirred tank reactors (CSTRs) based on input–output feedback linearization[28], control of anaerobic hybrid reactor in wastewater treatment and biogas production[29].

Studies show that fuzzy logic control is a promising way to solve industrial control problems, the use of these controllers in pilot-scale plants is essential to evaluate their potential value and fuzzy controller that would achieve the desired control performance. The authors concluded from few experiments that automation presented the same performance using either conventional linear methods or fuzzy logic methodology. However, these authors mentioned that this control problem seems to be destined to fuzzy logic because the linguistic form knowledge available. The objective of this study is application of fuzzy logic control of batch reactor and batch distillation column.

Fuzzy Logic Controller

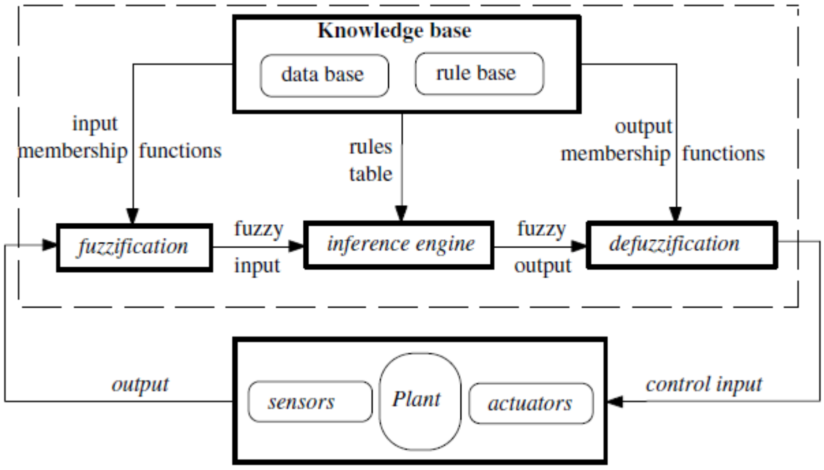
There is no general and mathematically optimal solution for the control if plant unit to be controlled is complex and highly nonlinear[30]. The modeling of the process and its solution become even more difficult if a sufficiently precise model is unknown or cannot be identified. It is well known however that in many cases a human can master the performance of such a plant using linguistic control algorithms that represent the operator knowledge and experience about the plant/unit by using If-Then rules. Fuzzy logic is a method of rule-based decision making used for expert systems and process control that emulates the rule-of-thumb thought process used by human beings. The first step in developing a FLC is to develop a rule base based on linguistic descriptions of control protocols acquired from domain experts. Fuzzy controllers are built from a set of if–then rules and are designed using an expert's knowledge and experience about controlling the variable. They are actually an expert system that uses fuzzy logic for its reasoning. A fuzzy controller has four parts as shown in Fig. 1 : the first a rule base, the second a fuzzy inference mechanism, the third an input fuzzification interface, and the fourth an output defuzzification interface. The rule base is designed by an expert who writes a set of if–then rules to describe what he thinks is the best way to control a variable. The controller interface applies the actions indicated by these rules one rule at a right time. The measured value of the controlled variable is "fuzzified" (ie, separated into several states such as high, medium or low), transforming its numeric values into fuzzy states, before it enters the controller. The knowledge base consists of the fuzzy linguistic control rules and the fuzzy reasoning mechanisms. The control rules are expressed in an if–then format and represent the accumulated control knowledge acquired from the domain experts. The fuzzy reasoning mechanism executes fuzzy logic operations so as to infer the appropriate fuzzy control action based on the fuzzy inputs provided. At the output of the controller, "defuzzification" combines the conclusions reached by the rules (ie, increase drug infusion rate slightly), converting them from their fuzzy state to a numeric value, so as to drive the infusion pump. The resulting set of fuzzy control actions are translated into non-fuzzy actions; the controller executes these actions on the process under study[30].

The reason why fuzzy logic is accepted is that it provides a constructive way of turning qualities into mathematics. Inaccurate or incomplete expert knowledge is formulated with help of a set of if–then rules. Each rule reflects a non-linear relationship between independent variables (inputs) and dependent variables (outputs) of the process or system under consideration. All rules together define a linguistic model. Then, the rules are transformed into a mathematical formalism by means of operations among membership functions, which are associated to the fuzzy sets. In general, fuzzy sets intersect each other and the shape of the set is chosen according to the effect of inputs on output.

[The expert knowledge is usually in the form of: IF (input1 is big) and/or (input2 is small) . . . (input N is medium) THEN (output1 is negative big) and (output2 is positive small) . . . (output M is zero).

Basically, fuzzy control rules provide a convenient way for expressing control policy and domain knowledge. Furthermore, several linguistic variables might be involved in the antecedents (before then) and the conclusions (after then) of these rules.

Multiple measured crisp inputs first have to be mapped into fuzzy membership functions. This process is called fuzzification. The fuzzification process requires good understanding of all the variables. Fuzzy logic's linguistic

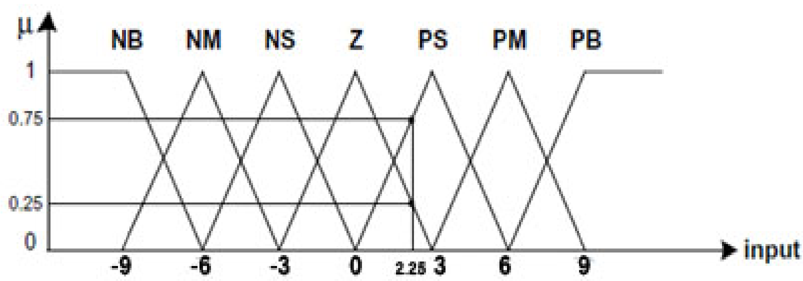


Figure(1) Structure of fuzzy controller[31].

terms are most often expressed in the form of logical implications, such as If–Then rules. These rules define a range of values known as fuzzy membership functions. Fuzzy membership functions may be in the form of a triangle, a trapezoid, a bell, or another appropriate form. $\mu(u_i)$ is *a* membership function, which is used to calculate the membership degree of the crisp input value. The range of $\mu(u_i)$ is between 0 and 1. In this study, the triangle membership function is used as shown in Fig. 2.

The triangle membership function is defined as below. Limits of the triangle membership functions are defined by Val1, Val2 and Val3.

$$\mu(u_i) = \begin{cases} \dfrac{u_i - Val1}{Val2 - Val1} & Val1 \le u_i \le Val2 \\ \dfrac{Val3 - u_i}{Val3 - Val2} & Val2 \le u_i \le Val3 \\ 0 & otherwise \end{cases} \qquad \ldots(1)$$



Figure(2) Seven levels of fuzzy membership function.

The inputs of the fuzzy controller are expressed in several linguistic levels. An example can be seen in Fig. 2. These levels can be described as positive big (PB), positive medium (PM), positive small (PS), zero (Z), negative small (NS), negative medium (NM) and negative big (NB). Each level is described by a fuzzy set. Linguistic variable input allows for the translation of a measured input into its linguistic description. For example, a measured input of 2.25 is translated into the linguistic variable of (0.25*Z, 0.75*PS) which can be interpreted as ‘‘positive small or may be zero’’. An input of 7.5 is a member in the fuzzy sets of the terms; (i) positive small to the degree of 0.75, (ii) zero to the degree of 0.25. The membership degree is calculated by using triangle membership function defined by Eq. (1). Experience and expertise are generally required for implementation of fuzzification in complex systems. The second phase of the fuzzy logic controller is its fuzzy inference where the knowledge base and the decision making logic reside. The rule base and the data base form the knowledge base. The data base contains descriptions of the input and output variables. In this study, the parameters of the membership functions for the input and output variables are stored in the data base. The count of data in the data base depends on how many inputs and outputs are used for the fuzzy logic controller and how many fuzzy sets are used for each input and output. The decision making logic evaluates the control rules. The control rule base can be developed to relate the output actions of the controller to the obtained inputs. The rule base used in this study is summarized in Tables (1) and (2). Each rule has the form IF E(t) is NB AND CE(t) is NB THEN u(t) is NB. Fuzzy inference uses linguistic terms (fuzzy sets), selected by fuzzification, for producing output linguistic terms by using the rule base. The rule base contains ‘‘if-then’’ rules between inputs and output. The outputs of the inference mechanism are fuzzy output variables. The fuzzy logic controller must convert its internal fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called defuzzification. One may perform this operation in several ways. One of the most common ways is to use the method of height. In the height method, first of all, the centroid of each membership function for each rule is evaluated, and then the final output (U_o) is calculated as the average of the individual centroid and weighted by their heights as follows:

$$U_o = \frac{\sum_{i=1}^{n} u_i \mu(u_i)}{\sum_{i=1}^{n} \mu(u_i)} \qquad \ldots(2)$$

where $\mu(u_i)$ is a minimum/maximum (depend on and/or operator) value of the membership degree of input values[30].

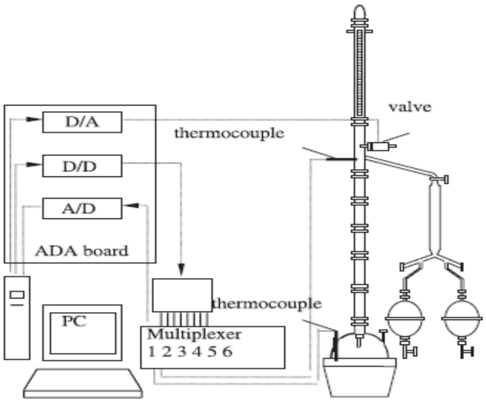
EXPERIMENTAL WORK

The performance of the fuzzy logic controller is experimentally demonstrated on two lab-scale systems. The systems are batch distillation column and batch reactor.

Batch Distillation Column

The experiments are carried out in a laboratory scale batch distillation column consists of a still pot, packed column and condenser as shown in Fig. 3 separating a methyl ethyl ketone (MEK)-water mixture. The batch distillation unit consists of a 0.4m height, 0.05m diameter packed column, thermally insulated was filled with

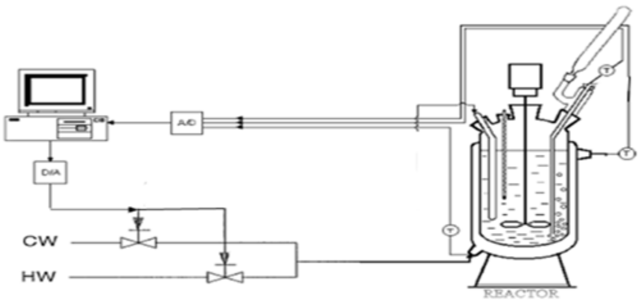
0.01m diameter glass rasching rings borsilicat glass column with a total condenser and 1.5 kW electrically heated reboiler. Three temperature sensors allow measurement of the temperature of still pot, packed section and the top product temperature. The temperature of column is controlled and manipulate the reflux ratio by control valve. A computer equipped with analog to digital converter A/D and digital to analog converter D/A converters provides real-time data acquisition and control.



Figure(3) Schematic Diagram of the batch Distillation column.

Batch Reactor

The batch reactor used in this research is a pilot system established in the laboratory as a test bed exhibiting typical characteristics of real chemical processes in industry. It consists of 10 liter borosilicate jacketed glass cylindrical reactor with a variable speed motor driven stirrer has height 0.32 m and 0.2 m inside diameter for the hydrolysis of acetic anhydride as shown in Fig. 4. It equipped with the stirrer of stainless steel which has six-bladed turbine. The stirrer operates with range of (0-350) rpm. The temperature of the batch reactor is controlled and manipulated the flowrate of tap water and hot water by two control valves. Thermocouples are installed to provide information on reactor temperature, as well as the inlet and outlet temperature of heating jacket. All measuring signals are fed to the process computer through A/D and D/A converters.



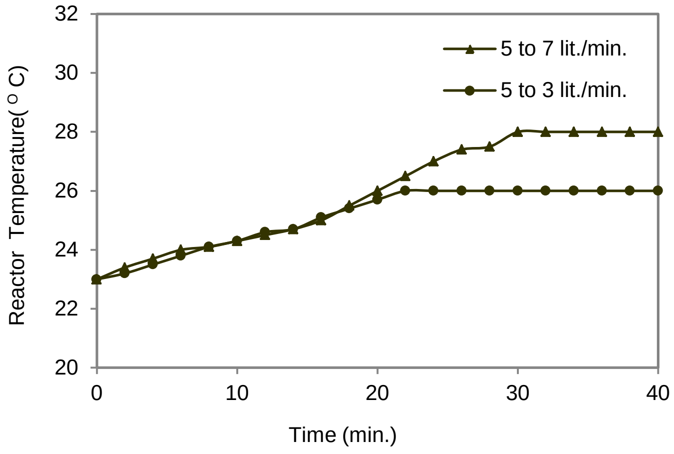
Figure(4) Schematic Diagram of the Batch reactor.

Results and Discussion

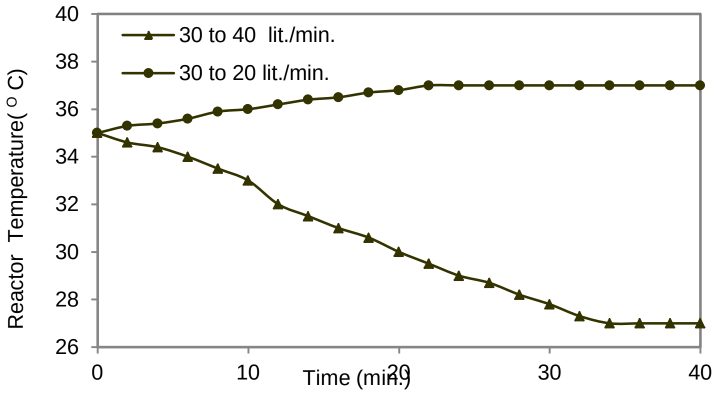
Open-loop experiments

The most common model identification methodology in continuous processes is the step response analysis. However, in batch processes, applying various manipulated variables profiles provides more information about the process. The open-loop experiments were carried out to determine process characteristics for the implementation of the fuzzy logic controller. For the batch reactor, the variables error and change of error are the control input variables. Firstly, their membership functions were evenly distributed over a normalized range [−9, +9]. In order to scale the membership functions for positive and negative linguistic values, step disturbances were imposed to the manipulated variables which is the flowrate of cooling and hot water and the temperature response of reactor behavior was analyzed. Four tests were carried out, two tests the cooling and hot water flow rate was increased by 30% of its steady state value and two tests the cooling and hot water flow rate was decreased by 30% of its steady state value. Figs. 5 and 6 show the process reaction curves obtained from the experimental runs. Fig. 5 shows the steps for closing and opening 30% the control valve for the hot water, in which the maximum flow rate was imposed at the reaction beginning (time = 0 min) and the minimum flow rate at the end (time = 40 min). In Fig. 6, it is observed that the valve is opened or closed at time equal to zero in which the minimum flow rate was imposed at the reaction beginning (time = 0 min) and the maximum flow rate at the end (time = 40 min). Change of cooling and hot water flow rate since the maximum flow rate variation is approximately 25 lit/min., the membership function limits were firstly set in the range [−9, +9]. However, since the positive range of the Z membership function of error is smaller than the negative one, the system tends to receive a full positive error (P) signal more frequently. It means that, according to fuzzy algorithm, a full P membership output is activated with higher frequency. Actually, fuzzy processing involves not only values obtained directly and exclusively from the membership functions since they can be adjusted by the scale factors in the structure. Therefore, the most important result from the open-loop experiments is the asymmetrical distribution of membership functions on the universe of discourse. Table (1) shows the rules of the fuzzy controller of batch reactor, which is designed depend on experimental data of open-loop case.

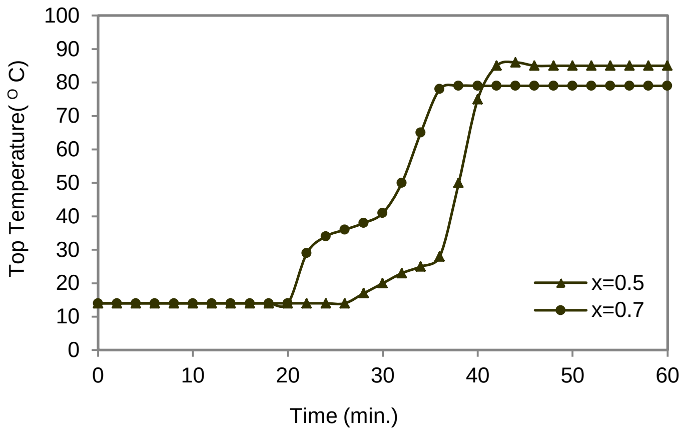
In the batch distillation column, four tests were carried out, two tests the reflux ratio was changed from 0.4 to 0.6 and two tests the mole fraction of MEK in the feed was changed from 0.5 to 0.7. The top temperature bottom temperature and still temperature responses of column behavior was analyzed. Figs. 7 to 10 show the process reaction curves obtained from the experimental runs. the membership function limits were firstly set in the range [−9, +9]. Table (2) shows the rules of the fuzzy controller of batch distillation, which is designed depend on experimental data of open-loop case.



Figure(5) Open loop reactor temperature response to positive and negative step change of hot water.



Figure(6) Open loop reactor temperature response to positive and negative step change of cooling water.



Figure(7) Open loop top temperature response at various mole fraction of MEK.

Table (1) Fuzzy controller rules for batch reactor

CE / E	**PB**	**PM**	**PS**	**Z**	**NS**	**NM**	**NB**
PB	PHB	PHB	PHB	PHB	PHM	PHM	PHM
PM	PHB	PHB	PHM	PHM	PHM	PHS	PHS
PS	PHM	PHM	PHS	PHS	PHS	PHS	Z
Z	PHS	PHS	PHS	Z	PCS	PCS	PCM
NS	PCS	PCS	PCS	PCS	PCS	PCM	PCM
NM	PCM	PCM	PCM	PCM	PCM	PCB	PCB
NB	PCB	PCB	PCB	PCB	PCB	PCB	PCB

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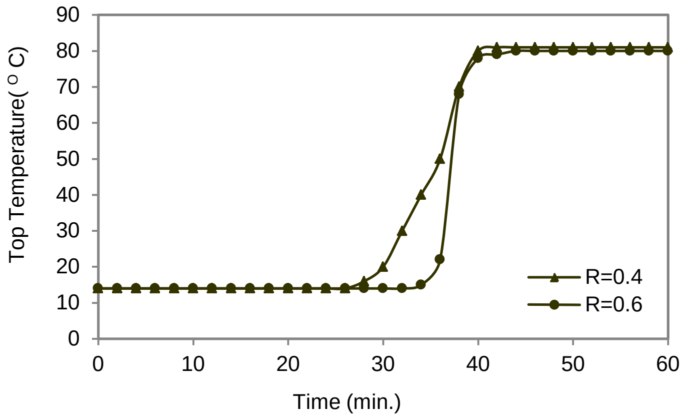
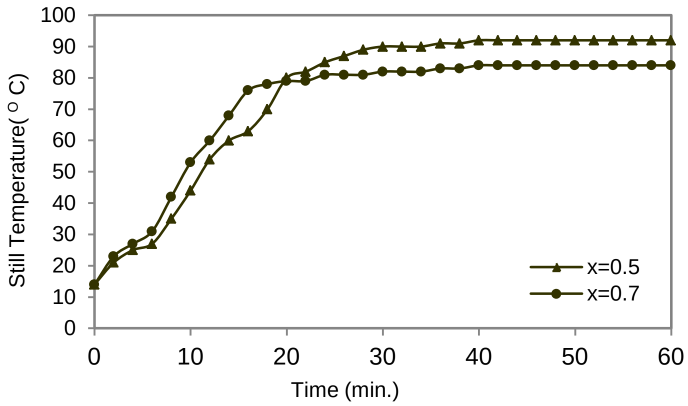
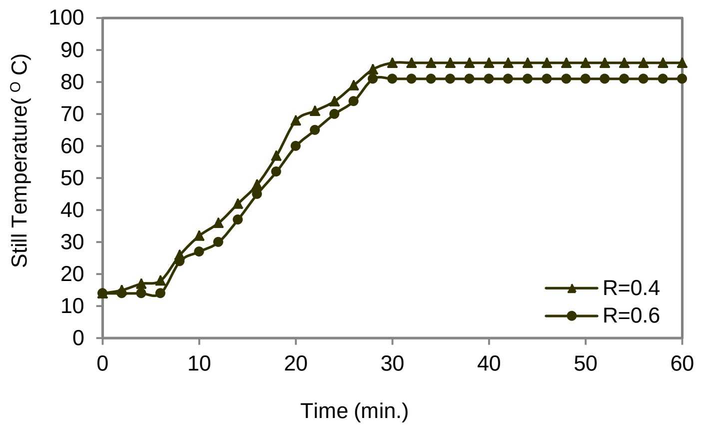


Figure(8) Open loop top temperature response at various reflux ratio.



Figure(9) Open loop still temperature response at various mole fraction of MEK.



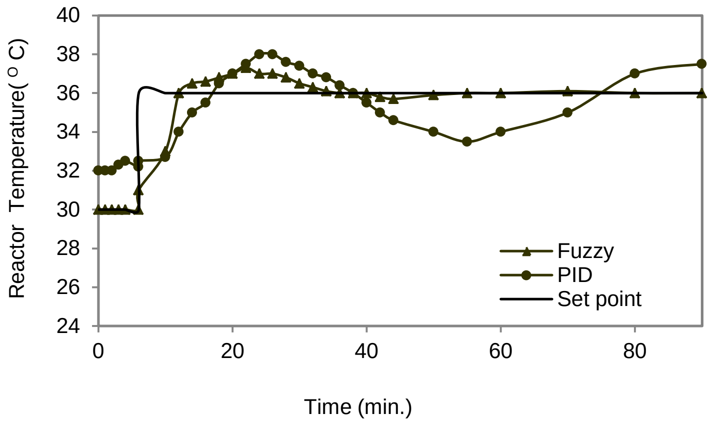
Figure(10) Open loop still temperature response at various reflux ratio.

Table (2) Fuzzy controller rules for batch distillation

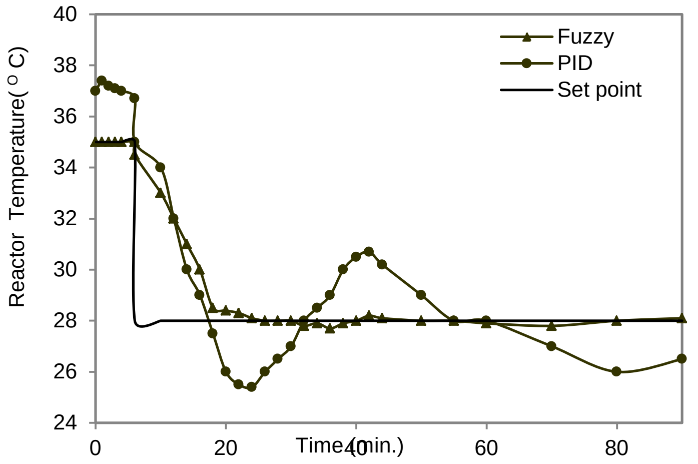
CE / E	PB	PM	PS	Z	NS	NM	NB
PB	PS	PS	Z	Z	Z	Z	Z
PM	PS	PS	Z	Z	Z	Z	Z
PS	PM	PM	PS	PS	Z	Z	Z
Z	Z	Z	Z	Z	Z	Z	Z
NS	PM	PM	PM	PS	PS	PS	PS
NM	PB	PM	PM	PM	PM	PM	PM
NB	PB	PB	PB	PM	PM	PM	PM

Closed-loop experiments

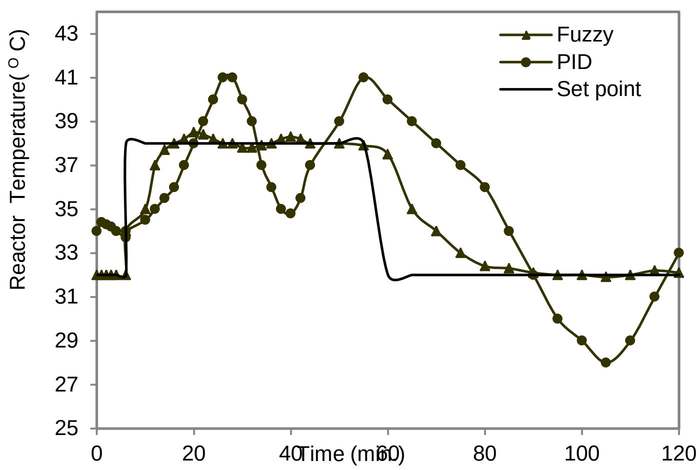
After the basic knowledge about the process was acquired from the open-loop experiments, the fuzzy logic controllers were constructed and implemented on the batch reactor and batch distillation systems. Testing of a controller should be performed to ensure some desired performance criteria, such as it is robust, closed-loop system must be stable, rapid, smooth response is obtained, offset and overshoot are eliminated, excessive control action is avoided. However, it is important to evaluate the robustness of these controllers with respect to changes in operating and process parameters. To examine and evaluate the control performance of the fuzzy controller over all regions, the setpoint of reactor temperature was changed from 30^{o}C to 36^{o}C, decreased from 35^{o}C to 28^{o}C and increased from 32^{o}C to 36^{o}C and then decreased to 32^{o}C. In Figure 11, the setpoint of reactor temperature is changed from 30^{o}C to 36^{o}C. The fuzzy controller of reactor temperature is presented and the control signals were calculated to regulate cooling water and heating water. The time spent for reactor temperature reach steady state is approximately forty minutes. The steady state errors of temperature +/- 0.2 degree Celsius as shown in Figure 11. The setpoint of reactor temperature is changed from 35^{o}C to 28^{o}C as shown in Figure 12 and the setpoint of reactor temperature is changed from 32^{o}C to 36^{o}C and then decreased to 32^{o}C as shown in Figure 13. The performance of the fuzzy controller with 49 rules was compared with the performance of the PID digital controller on two performance measures which are overshoot and integral absolute error IAE. The IAE was calculated for fuzzy and PID controllers and presented in Table 3. The IAE performance index shown in this table confirm the better performance of the fuzzy controller. The experimental results obtained from the fuzzy controller and the PID controller for a step setpoint temperature reactor change are shown in Figs. 11 to 13. A smooth and faster response was obtained without overshoot and control signal is also smaller in magnitude at the instant of temperature increase and settles down in shorter time in the fuzzy control in comparison with the PID controller. The PID controllers did not meet the needs of precise control and resulted in a large steady state error, large magnitudes of overshoots and settling times. As seen in Fig. 11, the fuzzy tuned controller has the quickest response, it seems the best control option and great improvements in responses can be obtained, since smaller magnitudes of overshoot and settling time were obtained. PID controller achieves an oscillatory response due to the high controller gain used. The results of the effects of the fuzzy controller are shown in Fig. 13. Reducing the rules yielded an unsatisfactory output response. The fuzzy controller leads to smaller temperature deviation than the conventional PID controller when the set point signal varies in step wise manner. The rules of batch reactor are presented in Table 1. The objective of the fuzzy controller is to provide stable control in a wide range of process operating points. The fuzzy controller demonstrates very good disturbance rejection and controller robustness is the ability to show sustained good dynamic performance in the face of parameter variations in the controlled process, given that the controller is tuned and set for the nominal process. These tests clearly show the superior performance and responses that the fuzzy controller is able to extract from the batch reactor process. The application of the fuzzy counterpart using membership functions previously found, results in a better temperature control than the conventional PID algorithm as seen on Figs. 11 to 13 and Table 3. The reaction temperature was kept closer to the set-point, despite the occurrence of a small offset. The cooling flow rate, under fuzzy control, was able to establish a smooth temperature behavior mainly in the batch final period.



Figure(11) Comparison between fuzzy controller and PID controller of reactor temperature for step change in setpoint.



Figure(12) Comparison between fuzzy controller and PID controller of reactor temperature for step change in setpoint.



Figure(13) Comparison between fuzzy controller and PID controller of reactor temperature for step change in setpoint.

To test the features of fuzzy controllers and their robustness on the control of the batch distillation, the experimental were carried out and results were compared also with the ones obtained using a traditional PID controller. Experimental results were obtained in the distillation column operated at atmospheric pressure. three tests were carried out, the setpoint of top temperature is increased from 60^{o}C to 70^{o}C, decreased from 70^{o}C to 60^{o}C and decreased from 70^{o}C to 60^{o}C and then increased to 70^{o}C. Figs. 14 to 16 show the column performance for a setpoint change in the top temperature. Time response, overshooting and the setting up of permanent oscillations were considered as main performance indicators. It can be seen that in this case the behavior of controllers is quite different.

The fuzzy controller shows the best behavior, characterized by some oscillations with amplitude value smaller than those of PID controller and decreasing with time. Fuzzy controller is the first controller to reach up the setpoint value followed by the

PID controller. The result indicates improved control with the fuzzy controller, the result of it combining information regarding the plant dynamics. The fuzzy controller are able to eliminate the offset in the top temperature practically without any overshoot. However, the fuzzy controllers can take care of a nonlinear model of the process and also compute the manipulated variables rapidly. Due to this disturbance, the top temperature start deviating from the setpoint shortly after the introduction of the disturbance. But, the controller is able to bring the temperature back to their setpoint. The result indicates improved control with the fuzzy controller, the result of it combining information regarding the plant dynamics. Figs. 15 and 16 show the same results, but using a disturbance of setpoint of the top temperature of distillation column. These Figures show that the fuzzy controller presents better control performance than that of the PID controller. To show the effectiveness of fuzzy controller further, and it is found that the magnitude of offset is much smaller than that of PID controller.

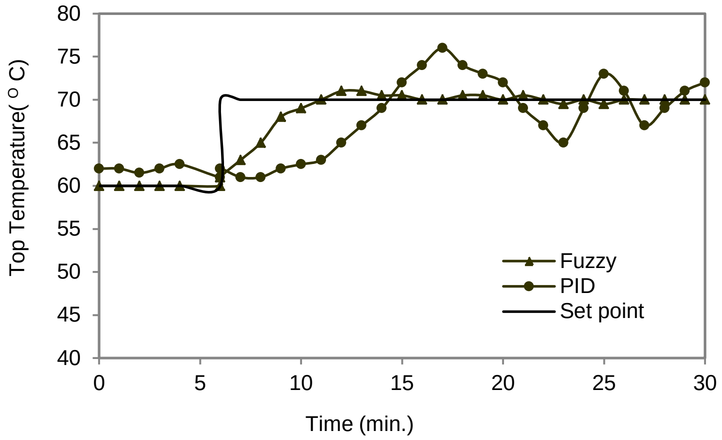
The quantitative performance values, IAE, for the fuzzy and PID controllers are given in Table (3). The control of distillation temperature using PIDs are not significantly worse than that of using fuzzy method . The control of the processes using PID showed a large degraded performance, as displayed in figures. From the performance of the PID controller, it can be seen that the temperature has severe non-linear dynamics that depends on operating point. Figs. 14 to 16 illustrates the difficulty in controlling this process with fixed PID. We compare the behavior of PID and fuzzy controller in this figures.

This figure shows clearly the advantage of the fuzzy controller over the conventional PID velocity form controller. Due to the characteristics of the fuzzy controller, it was applied to a servo control problem, in spite of the nonlinear and unsteady behavior of the batch column. The controller must keep the temperature close to a step setpoint trajectory (70, 80).

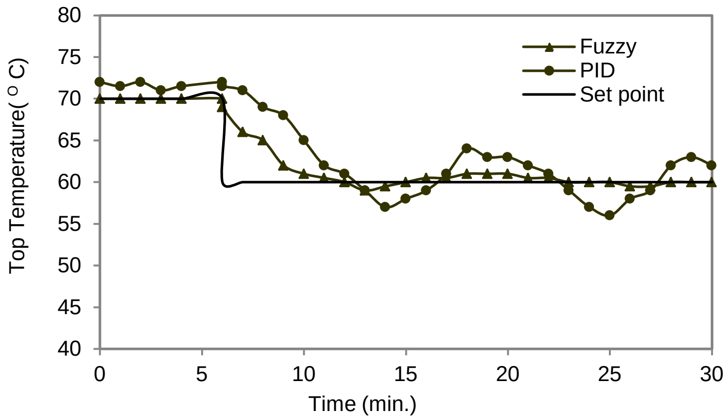
Fig. 16 shows that the fuzzy controller was able to deal successfully with the variable setpoint strategy, although using constant design parameter values. A smoother behavior in the control action was reached with the fuzzy control loop implementation. The fuzzy controller responds as quickly as PID. They indicate that the fuzzy give smoother and better control performance than the PID controllers with smaller IAE error values, when disturbances are introduced into the system.

The figures illustrate that the fuzzy method brought the distillation temperature to the set points by gradual increase of the heat reboiler which give smooth control response.

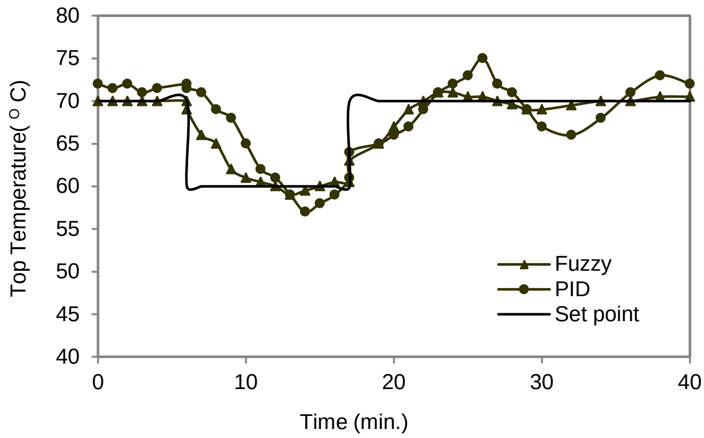
The PID control in turn brought the distillation temperature to the set point by rigorous adjustment of the heat reboiler causing overshoot in the process response with a long response time. They indicate that fuzzy controller gives less error and gives better control performances than the PID controllers, similar to the disturbance case study. These results also show the robustness of the fuzzy controller in dealing with disturbances it during training. Comparing these areas of the results illustrates the significant improvement of controller using a fuzzy model over PID controller.



Figure(14) Comparison between fuzzy controller and PID controller of distillation temperature for step change in setpoint.



Figure(15) Comparison between fuzzy controller and PID controller of distillation temperature for step change in setpoint.



Figure(16) Comparison between fuzzy controller and PID controller of distillation temperature for step change in setpoint.

Table (3) The integral of the absolute value (IAE) for the control methods

Process	Disturbance Value of Setpoint	Fuzzy Controller	PID Controller
Batch Reactor	30 to 36^{o}C	0.492	2.043
	35 to 28^{o}C	0.752	2.302
	35 to 28^{o}C then 32^{o}C	1.395	5.712
Batch Distillation Column	60 to 70^{o}C	0.342	1.692
	70 to 60^{o}C	0.367	1.417
	70 to 60^{o}C then 70^{o}C	0.648	1.833

CONCLUSIONS

The application of fuzzy controller to batch processes is investigated. Both the fuzzy and PID controllers have been implemented and the controller performance under multiple changes in setpoint and the effect of this disturbance has been investigated. This paper has demonstrated the usefulness and effectiveness of applying fuzzy controller in of batch reactor and batch distillation column. The fuzzy controller can be developed by using expert knowledge to obtain values of the controller parameters without the knowing the model and the experiment provides a detailed case study in which fuzzy method were applied to the batch control processes. Both the fuzzy and PID controllers have been implemented and the controller performance under multiple changes in setpoint and the effect of this disturbance has been investigated. The process was successfully brought back to the setpoint after a step disturbance in the setpoint by using fuzzy controller. The integral of the absolute value of the error (IAE) for performance measure indices is used to make a fair comparison between the two control methods. It can be clearly seen that the PID controller has a higher IAE value compared to the fuzzy controller. Comparison of performance with the conventional PID controller indicated that fuzzy controller was more robust than the PID controller and gave better results in cases involving disturbances. The results so obtained show that the PID controller gives high overshoot and settling time. Better disturbance rejection results were shown by the fuzzy controller and produced smoother controller moves than its PID equivalent. The fuzzy logic controller give fast response for the batch processes with less offset value and advantages of fuzzy controller is not require any tuning of the control parameters while the PID does require that.

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