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MODELLING AND CONTROL FOR COMPOSITION OF NON-ISOTHERMAL CSTR BY USING FUZZY

Nasser Mohamed Ramli
Chemical Engineering Department, Universiti Teknologi PETRONAS,
32610 Bandar Seri Iskandar, Perak, Malaysia

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ABSTRACT

As a matter of fact, several chemical or petrochemical industries are still using the old technology which are conventional control; one of it is PID controller. PID controller stills had a lot of weaknesses that need to be concerned, which it's the accuracy and it's precision. Due to this reason, the researchers had found the initiative to solve this problem by creating the Artificial Intelligence (AI), one of it is the Fuzzy Logic. For this research paper, it will introduces the concept of Fuzzy Logic approach towards the control system of non –isothermal continuous stirred tank reactor (CSTR). This simulation study had been made by using the MATLAB SIMULINK, and there will be a comparison with PID controller in order to justify the effectiveness of the modern technology concept in the control system.

KEYWORDS: Non-isothermal CSTR, PID Controller, Fuzzy Logic

INTRODUCTION

In the industrial society, people are searching on how to produce high amount production without using a lot of money (spending this money to cover the loss of production and any errors in the system). Due to that reasons, the controlling of the reactor is very important to the engineers and researchers.

Continuous stirred tank reactor (CSTR) is the most popular chemical reactor compared to the others. Besides, this reactor exposed with a complicated nonlinear dynamic characteristic. This will help the researchers to introduce the opportunity for a diverse range of process dynamic. Beside its model has become one of the standard applications for theoretical results in the area of the nonlinear control [10]. However, if lacking in understanding the operation of CSTR may make difficult to develop a suitable control strategy. Besides, in order to achieve an effective control system of CSTR required an accurate mathematical model.

In any cases, to develop mathematical model is a must in order to control the reactor. The model need to be controlled in order to use the designing control law. In order to achieve an excellent controller required a very accurate and precise control system. In deriving the mathematical model, the designer follows two models, the researcher must follows based on data from the suitable principles or equations and the experimental data from the investigation. In any cases, to develop mathematical model is a must in order to control the reactor.

However, it is not easy to develop the mathematical model specially to study the complicated system. This is because it very complex and consume a lot of time as it requires several expectations. This problems had led researchers to investigate and study by exploiting the Artificial Intelligence (AI), one of it is the fuzzy logic tools in modelling complex system.

APPROACH AND METHODS

Mathematical Equation Model of non-isothermal CSTR

As for this research, a chemical reactor, Continuous Stirred Tank Reactor is considered due to the dynamic behaviour and its characteristic that had been studied extensively. This reactor is operated at non-isothermal conditions where there is a changes of temperature in the reaction.

A model of CSTR is required for the process control system. The mathematical model equations are obtained by the components mass balance and energy balance principle in the reactor [10]:

The mathematical model of non-isothermal CSTR is:

$$\frac{dCa}{dt} = \left(\frac{F}{V}\right) \times (Caf - Ca) - k0.\,exp\left[-\frac{Ea}{R.(T+460)}\right].Ca \tag{1}$$

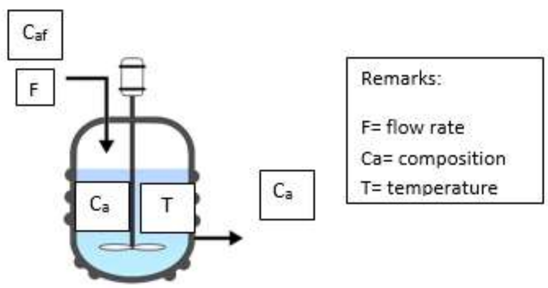

Figure 1: Project Process Flow

From the figure above, we can see that the Concentration, Ca will the output, However, it should consider that our concern is to control the concentration of this reactor to achieve at certain set point.

Fuzzy Logic Approaches

Fuzzy logic control is a methodology bridging artificial intelligence and traditional control theory. This generally referred as logical system and complex control problems which is an extension of multivalued logic [8]. This methodology is usually applied in the only cases when accuracy is not of high necessity or important. Wide spread of the fuzzy control and high its effectiveness of its application in a great extend is determined by formalization opportunities of necessary behaviour of a controller as a flexible (fuzzy) representation. This representation usually formulated in the form of logical (fuzzy) rules under linguistic variable of a type “If A then B”. Basically, the fuzzy logic is all about the relative importance of precision.

This shows that this control can provides a practicable way to understand and manually influence the mapping behaviour. In other words, the fuzzy logic can use simplify methodology to describe the system of interest rather than analytical equations in which easy to the user to understand and applied. The advantage, such as robustness and speed, the fuzzy logic is one of the best solutions for this process modelling and control.[8]

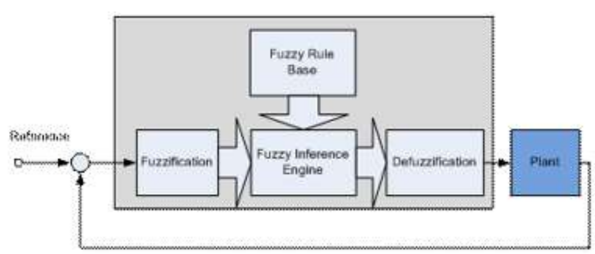

Figure 2: Fuzzy Logic Concept

STAGE 1: Develop S-function for Concentration of Non-isothermal CSTR

The simulation model in MATLAB Simulink will be build based on these predefined parameters and operating conditions:

Table 1. Variables involve

Operating Variables	Notation	Units	Value
Concentration of reactant A in the exit stream	Ca	lbmol/ft^3	-
Temperature	T	oF	-
Activation energy of reactant A	Ea	BTU/Ibmol	32400
Frequency factor	K0	hr^{-1}	15e12
Universal gas constant	R	BTU/Ibmol-oF	1.987
Volume	V	ft^3	750
Volumetric feed flow rate	F	ft^3/hr	3000
Concentration of reactant A in the feed stream	Ca_f	lbmol/ft^3	0.132
Feed temperature	T_f	oF	60
Cross sectional area of the reactor	A	ft^2	1221

The data from Table 1, supposed to model the non-isothermal CSTR from equation (1);

The S-function Simulink design for concentration of non-isothermal CSTR;

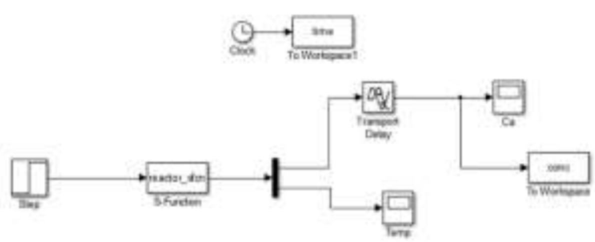

Figure 3. Simulink design for set-point (benchmark)

STAGE 2: Creating Transfer Function
There are 3 parameters that need to be concerned in order to create transfer function (TF):
1. Process gain, Kp
2. Time delay, τ_d
3. Time constant, τ_c

$$TF = \frac{Unstable\ process\ gain, Kp}{Process\ time\ constant, \tau_c\,(s)+1}\ e^{-Time\ delay, \tau_d (S)} \quad (2)$$

The reactor process transfer function (TF):

TABLE 2. The parameters in the transfer function

Unstable process gain, Kp	Process Time Constant, τ_c	Time Delay, τ_d
0.1287	0.2	3

$$Transfer\ function\ (TF) = \frac{0.1287}{0.2s+1}\ e^{-3S} \qquad (3)$$

The value in this Table 2 used to calculate the transfer function by using this equation (2), in order to get the proportional gain, Kc, integral time, Ti and derivative time, Td.

STAGE 3: Create SIMULINK design with PID controller (Adaptive)

As for this project, selected PID Control strategy application for this reactor, which is the adaptive control with respect to the set point and disturbance.

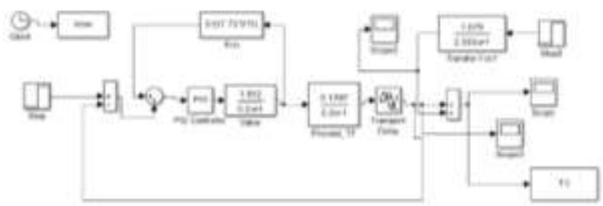

Figure 4. Simulink design with Adaptive PID controller

STAGE 4: Create SIMULINK design with Fuzzy Logic Controller

This project basically to design the PID controller with a simple modification of fuzzy logic based on IF-THEN rules into the control system. Besides it does not have analytic formula to use for control specification and stability analysis. The fuzzy PID controller are the accepted extensions for the conventional control system, which prevent the errors and increase of its precision, with just a simple analytical formulas as their final result of the design.

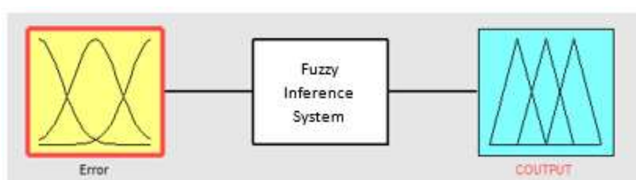

Figure 5. The concept of mamdani based fuzzy inference system

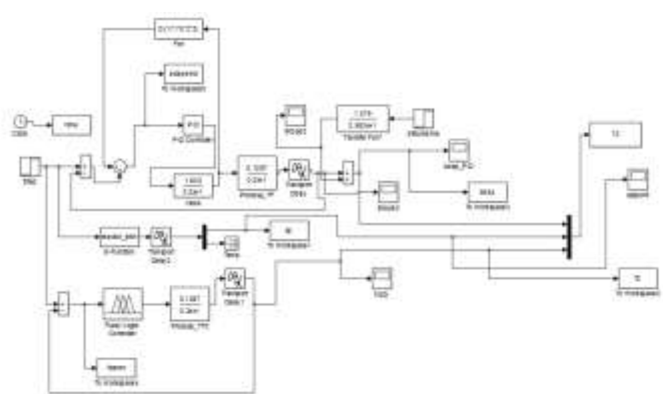

Figure 6. Proposed Simulink design of fuzzy logic controller and Adaptive PID controller

Figure 5 shows the concept of fuzzy inference system that had developed for this project. Figure 6 shows the overall Simulink design, based on the transfer function of this project (keeps the general design of PID controller as shown figure 3)

TABLE 3. The linguistic variable for fuzzy set rules

Variable	NH	NL	ZERO	PL	PH
Error (Error)	Negative High	Negative Low	Zero	Positive Low	Positive High
Output (Controller Output)	Negative High	Negative Low	Zero	Positive Low	Positive High

The fuzzy set rules (base) had been described as below:
1. IF "Error is very NH" THEN "Controller Output is very PH"
2. IF "Error is very NL" THEN "Controller Output is very PL"
3. IF "Error is very ZERO" THEN "Controller Output is very ZERO"
4. IF "Error is very PL" THEN "Controller Output is very NL"
4. IF "Error is very PH" THEN "Controller Output is very NH"

RESULTS AND DISCUSSION

Figure below is result from Stage 1 based on the design, Figure 7, to get the set point for the concentration.

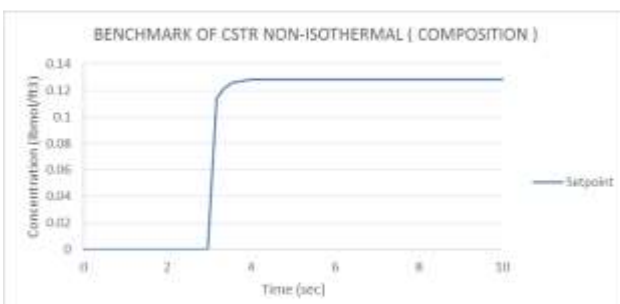

Figure 7. Result Benchmark of non-isothermal CSTR Concentration

From the Figure 8, is the result of Adaptive PID controller without disturbance. The concentration is most almost reach to the set-point, 0.1287. It just a small amount of steady state error, 0.31%.

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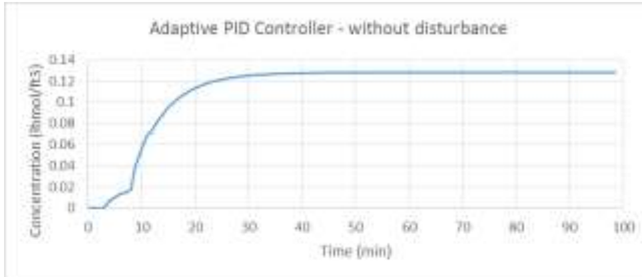

Figure 8. Result Adaptive PID Controller without disturbance

Meanwhile, this Figure 9 is the result of Adaptive PID controller with disturbance. The concentration response of the system generates 5.8% of steady state of error.

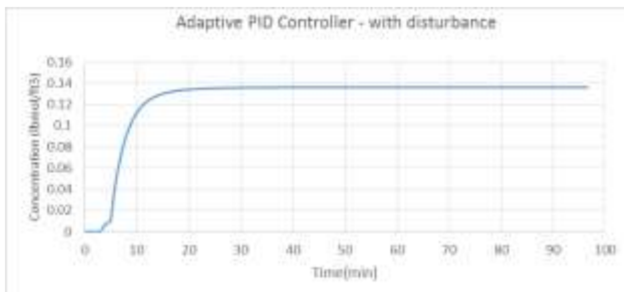

Figure 9. Result Adaptive PID Controller with disturbance

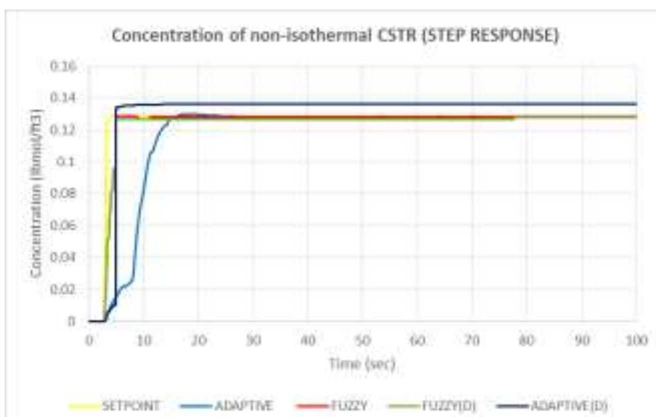

Figure 10. Graph of concentration of CSTR controlled by fuzzy logic controllers

Table 4. Summary result of controller tuning for concentration in CSTR

	Fuzzy logic	Adaptive	Fuzzy logic due to disturbances	Adaptive due to disturbances
Rise time	9.51E-08	0.045	5.5E-15	0.023
Settling time	0.127	0.128	0.128	0.136
Peak time	0.127	0.128	0.128	0.136
IAE	12.30	13.21	12.42	12.54

As we can see from the figure and the result, it had shown us that, by using the fuzzy logic controller, generates small of Integral Absolute Error, IAE, 12.30 compared with the Adaptive controller in which generate 13.21. But if creating the control system with disturbance, the fuzzy logic will generates, 12.42 and Adaptive PID controller generates, 12.54. A huge effect from the Adaptive controller almost 5% decreasing but not in the fuzzy logic system, it become worst. In meantime, fuzzy logic's settling time is very quick compared to the others.

CONCLUSION

As for the conclusion, we could find that the fuzzy logic can gives the most favourable result. This is because the IAE is very small, the settling time settle quickly and less oscillation. The target of the concentration is 0.1287 lbmol/ft3 with time delay of 3 minute. So based on the result, the fuzzy logic concept has proven to us that it can be an effective solution to a complex control problem. Thus it is an alternative to the use of another controller. It can brings more benefits in the development of industrial process control system.

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