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INTELLIGENT CONTROL OF TEMPERATURE IN PRODUCTION OF GMS FROM CPO USING FUZZY LOGIC

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ABSTRACT

Glycerol Mono Stearic (GMS) is a kind of surfactant which can be made from derivatives of Crude Palm Oil (CPO). Making GMS using semi-batch reactors involves reaction, purification, finishing of product, and recycling of catalyst. During reaction, materials which are derivates of CPO and catalyst are fed into the reactor, and some variables such as temperature are controlled in such a way to optimize the process. The objective of this study is to find a temperature control method which gives the best performance. To achieve this objective, some intelligent control methods are considered based on fuzzy logic and their simulation results are described. The intelligent controllers are designed to satisfy two design specifications those are: keeping the temperature close to the reference temperature under variation of environment, and making the temperature follow the reference temperature change as fast as possible. Study on performance against the variation of dead-time due to remotely located oil heater from the reactor is also reported. The result of this study concludes that the direct PI fuzzy controller and the PID fuzzy controller are able to eliminate steady state error while the direct PD fuzzy controller hardly eliminates steady state error. From the result of this study it is recommended that the PI fuzzy controller should be used when the oil heater is located near by the reactor while the PID fuzzy controller should be used when the oil heater is located remotely from the reactor.

Keywords: *Glycerol Mono Stearic (GMS), surfactant, CPO, semi-batch reactor, intelligent control, fuzzy logic, temperature, dead-time, direct PI fuzzy, PID fuzzy, direct PD fuzzy.*

INTRODUCTION

Glycerol Mono Stearic (GMS) is non-ionic surfactant which is commonly used in shampoo as pearlizing agent, emulsifier and lotion, and also in food as opacifier such as in ice cream and butter (Kirk-Othmer, 1999). Some experimental studies have been conducted at Indonesian Institute of Sciences (LIPI) concerning production process of GMS from derivatives of Crude Palm Oil. Hilyati et. al. have conducted laboratory scale experiments and reported that GMS could be made from derivatives of Crude Palm Oil through esterification reaction (Hilyati, et.al., Yogyakarta, 6-7 November 2001). When their procedure, which had been proven in laboratory scale to be valid, was applied to a mini plant producing GMS many problems rose. One problem is related to temperature control of the reactor used, since its temperature is controlled using heated oil which is supplied by an oil heater located a part from the reactor. The dynamical model of the temperature of reactor and heater may be identified in on-line manner using an on-line process identification method (Estiko Rijanto. Serpong, 2004). Because of the remote location between the reactor and the heater, the dynamical model is characterized by a dead-time.

This paper addresses research on temperature control of reactor in the mini plant producing GMS from derivatives of CPO. The purpose is to find a control method which best controls the temperature of reactor in the mini plant. One way to compensate the effect of the dead-time is using Smith compensators (O.J.M. Smith. 1959). Another way is by the use of fuzzy logic (Zadeh, L.A., 1973; Mamdani, E.H. and S.Assilian. 1974; Lee. C.C., 1990 a; Lee. C.C., 1990 b). Three fuzzy logic based controllers are considered and their performances are investigated through analytical approach as well as numerical simulation approach.

This paper is organized as follows: section 2 summarizes the process of making GMS using derivatives of CPO conducted in this research, section 3 describes a method to design intelligent

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temperature controllers based on fuzzy logic suitable for controlling the reactor, section 4 reported simulation results, and section 5 draws conclusion and recommendation.

PROCESS DESCRIPTION

The experimental assembly is consisted of a 500 litter double jacketed reactor and an oil heater as shown in Figure 1.

The reactor has the diameter of 119.4 cm and the height of 167.2 cm. Stainless steel is used as reactor material with 0.3 cm thickness. This reactor uses glass wool of 10 cm thickness for its insulation. The distance between the inner jacket and the outer jacket where it is filled with oil is around 10 cm. The amount of 220 litter of oil is needed to fill the chamber between the inner jacket and the outer jacket.

To increase the temperature of the reactor, high temperature oil is supplied from the oil heater into the oil chamber in the reactor. After the heat is exchanged in the chamber, the oil is then fed back into the heater where it is heated again by electrical elements. This constructs a heating cycle where the heat created by electrical elements in the heater is delivered to the reactant inside the reactor. *Transcal N* oil is used as heating oil since it is considered as high quality heat transfer oil. It possesses low vapor pressure, good thermal stability, high specific heat and high thermal conductivity. Conversely, to reduce the temperature of the reactor, low temperature oil is supplied from the oil heater into the oil chamber in the reactor. After the heat is exchanged in the oil chamber, the oil is then fed back into the heater where it is cooled again by cooling water.

This constructs a cooling cycle where heat of the reactant in side the reactor is thrown away through the cooling water.

CONTROLLER DESIGN

It is assumed that the plant to be controlled can be expressed as follows:

$$Y(s)=\frac{K}{1+Ts}\cdot e^{-Ls}U(s)\Rightarrow Y(s)=P(s)U(s) \qquad (1)$$

A controller is designed to construct a feedback control system shown in figure 2 which fulfils the following design specifications:

1. It follows step like reference signal: tracking performance.
2. It eliminates effect of step like input disturbance: regulating performance.
3. It maintains stability against variation of dead time up to certain value.

In this figure, r denotes reference signal equivalent to the temperature setting point (°C), u denotes control output calculated by the controller, d denotes input disturbance such as change in environment (room) temperature, u_r is real control input to the plant, z is controlled variable which is temperature of the reactant inside the reactor, n is measurement noise, and y and e represent the measured signal and error between the reference signal and the measured signal respectively.

Intelligent control of temperature in this paper means that the controller has the ability like a human being to be adaptable to system change including: change in room temperature and change in value of dead time due to different distance between reactor and oil heater. Fuzzy logic is used to design intelligent controller because fuzzy based controllers are characterized by:

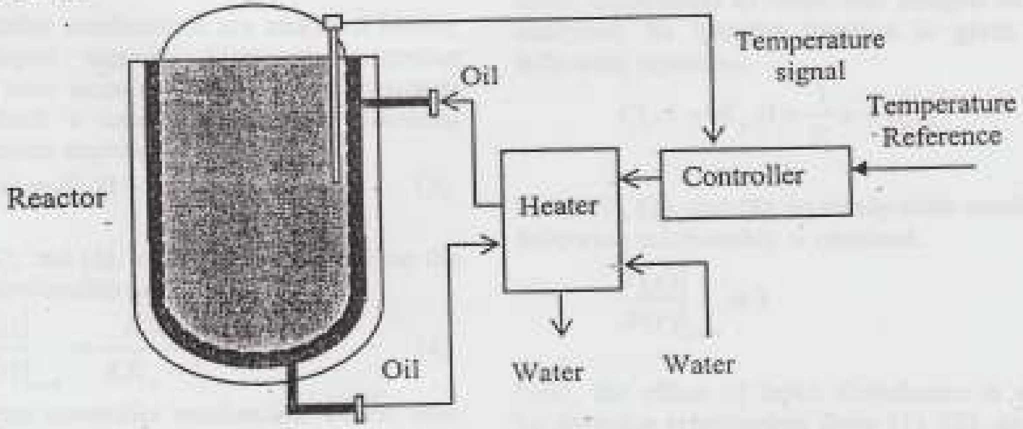


Figure 1. Experimental Assembly.

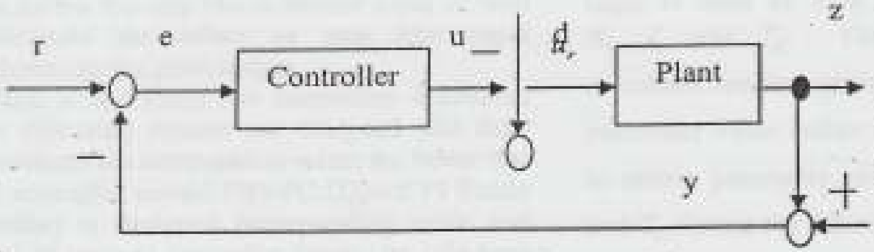


Figure 2. Feedback Control System.

1. It can express linguistic control law based on know-how from an expert.
2. It does not require a sophisticated mathematical model of the controlled plant.
3. It is adaptable to system characteristic and circumstance change.

A commonly used fuzzy controller incorporates error $e(t)$ and its differential $\frac{de(t)}{dt}$ as controller inputs to produce a controller output $u(t)$. However, integral of error $\int e(t)dt$ may also be used as controller input. Choosing controller input is one significant step in fuzzy controller design, and in this paper choosing controller input is conducted based on analysis of controller mechanism using linear control theory approach.

Assuming a linear controller $C(s)$ is used, the following relationship is obtained.

$$Y(s) = \frac{1}{[1+P(s)C(s)]}[P(s)C(s)R(s) - P(s)D(s) + N] \quad (2)$$

Three controller mechanisms are analyzed having different input signals. First, a controller mechanism uses error and differential of error is analyzed. Such a controller has the following transfer function expression.

$$C(s) = K_p\{1 + T_d s\} \quad (3)$$

From (1), (2), and (3), in steady state condition the following relationship can be derived

$$\left.\frac{Y(s)}{R(s)}\right|_{s=0} = \frac{KK_p}{KK_p - 1} \neq 1 \quad (4)$$

Therefore, the controller mechanism which uses error and differential of error as its control inputs is not recommended to be used, since it leaves steady state error.

Second, a controller mechanism uses error and integral of error is analyzed. Its transfer function is given by the following equation.

$$C(s) = K_p\{1 + \frac{1}{T_i}s\} \quad (5)$$

Deriving steady state condition from (1), (2), and (5), the following relationship is obtained.

$$\left.\frac{Y(s)}{R(s)}\right|_{s=0} = 1 \quad (6)$$

Next, the effect of input disturbance is analyzed by deriving relationship from (1), (2), and (5) to obtain steady state condition as follows.

$$\left.\frac{Y(s)}{D(s)}\right|_{s=0} = 0 \quad (7)$$

From (6) and (7), it is evident that the controller mechanism expressed in (5) can make the plant output follow the step like reference input as well as eliminate the effect of step like input disturbance on the plant output.

Third, a controller mechanism which uses error, differential of error, and integral of error is analyzed. Its transfer function is given by the following equation.

$$C(s) = K_p\{1 + \frac{1}{T_i}s + T_d s\} \quad (8)$$

From (1), (2), and (8), in steady state condition the following relationship is obtained.

$$\left.\frac{Y(s)}{R(s)}\right|_{s=0} = 1 \quad (9)$$

Next, the effect of input disturbance is analyzed by deriving relationship from (1), (2), and (8) to obtain the following steady state condition.

$$\left.\frac{Y(s)}{D(s)}\right|_{s=0} = 0 \quad (10)$$

From (9) and (10) it is obvious that the controller mechanism expressed in (8) can make the plant output follow the step like reference input as well as eliminate the effect of step like input disturbance on the plant output.

Thus, in this study two controllers illustrated in the following figures are designed and their performances are compared to select the better one.

A controller named DPI-FC (Direct PI Fuzzy Controller) is designed incorporating error and integral of error as controller inputs. Its rule base is listed in Table 1.

The meaning of linguistic label in table 1 is as follows: NB is negative big, NM is negative medium, ZO is zero, PM is positive medium, and PB is positive big. Membership functions of controller input and controller output of the DPI-FC are shown in the following figure.

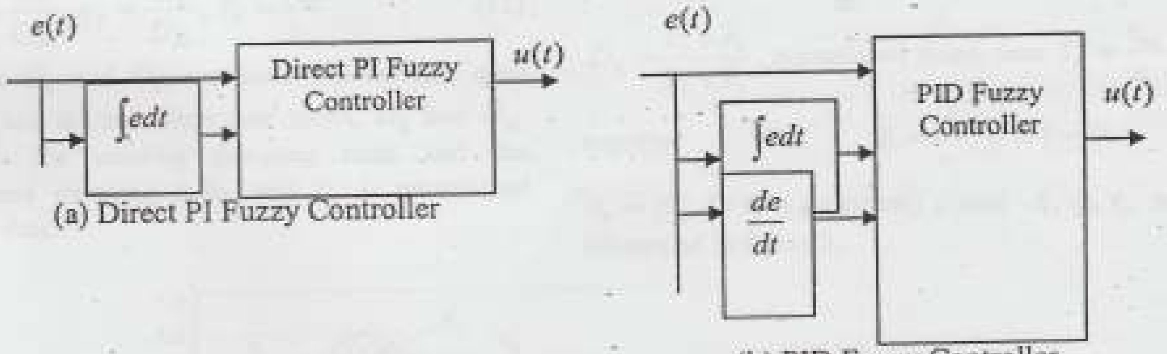
On the other hand, the PID fuzzy controller has the same structure expressed in (8), and fuzzy logic is used to tune the parameter values of K_p, T_i and T_d. The PID fuzzy controller calculates revision constant (C_p, C_i, C_d) of each parameter value before tuning (K_{po}, T_{io} and T_{do}) to obtain parameter values after tuning (K_p, T_i and T_d) using the following equation.

$$\left.\begin{aligned} K_p &= C_p K_{po} \\ T_i &= C_i T_{io} \\ T_d &= C_d T_{do} \end{aligned}\right\} \qquad (11)$$

The values of the revision constant (C_p, C_i, C_d) are calculated based on the rule base shown in Table 2 [9].

Table 1. Rule Base for Direct PI Fuzzy Controller.

"Thermal Force" u [Volt]		Integral of error $\int edt$				
		NB	NM	ZO	PM	PB
Error e(t) [°C]	NB	NB	NB	NB	NM	ZO
	NM	NB	BN	NM	ZO	PM
	ZO	NB	NM	ZO	PM	PB
	PM	NM	ZO	PM	PB	PB
	PB	ZO	PM	PB	PB	PB



(a) Direct PI Fuzzy Controller

(b) PID Fuzzy Controller

Figure 3. Block Diagram of Two Fuzzy Controllers.

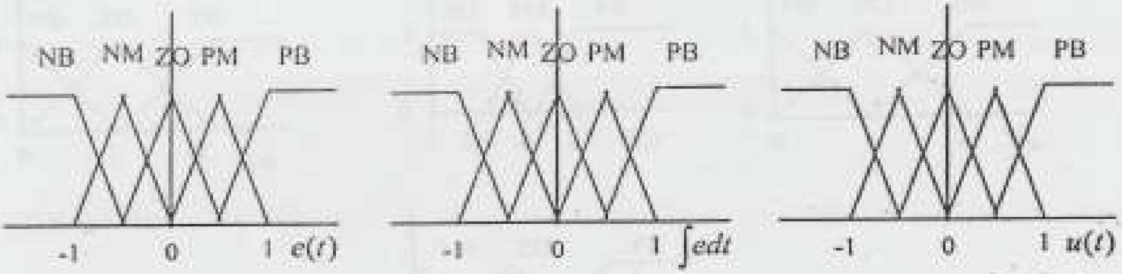


Figure 4. Membership Functions for Direct PI Fuzzy Controller.

Table 2. Rule Base for the PID Fuzzy Controller.

Rule	Fuzzy inputs (linguistic value)			Revision constant (linguistic value)		
	η_{OS}	η_D	T_R	C_p	C_i	C_d
Rule 1	PB	-	ZO	NB	ZO	ZO
Rule 2	PB	PM	PB	ZO	PB	ZO
Rule 3	PB	PM	ZO	ZO	PB	PB
Rule 4	PB	PM	NB	NB	PB	ZO
Rule 5	PB	ZO	PB	ZO	PB	ZO
Rule 6	PB	ZO	ZO	ZO	PB	PB
Rule 7	PB	ZO	NB	NB	ZO	ZO
Rule 8	ZO	PB	PB	PB	NB	ZO
Rule 9	ZO	PB	ZO	ZO	NB	ZO
Rule 10	ZO	PB	NB	NB	NB	ZO

The fuzzy inputs are:

$$\eta_{OS} = \frac{O_S}{O_{Sr}}, \eta_D = \frac{D_R}{D_{Rr}}, T_R = \frac{\tau_{60}}{\tau_r} \qquad (12)$$

where: O_S and O_{Sr} represent the existing over shoot and the reference over shoot, D_R and D_{Rr} denote the existing damping ratio and the reference damping ratio, and T_R is normalized rising time.

Overshoot $O_S = \frac{\bar{e}_2}{\bar{e}_1}$, damping ratio $D_R = \frac{\bar{e}_3 + \bar{e}_4}{\bar{e}_2 + \bar{e}_3}$, normalized rising time $T_R = \frac{\tau_{60}}{\tau_r}$, together with $\bar{e}_i = \frac{A_i}{\tau_i}, (i = 1 \sim 4)$, $\tau_r = \gamma T_s, (\gamma \text{ is a constnat})$, and A_i, τ_i, τ_s are illustrated in figure 5.

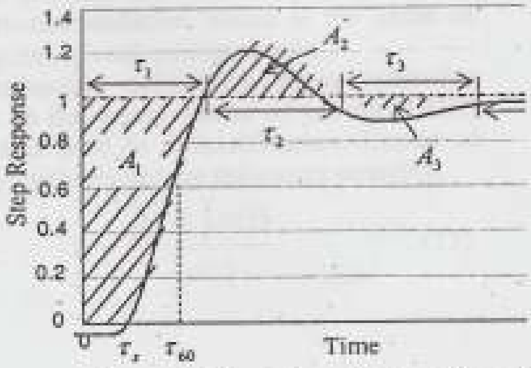


Figure 5. Illustration of Quantities Used in Fuzzy Inputs.

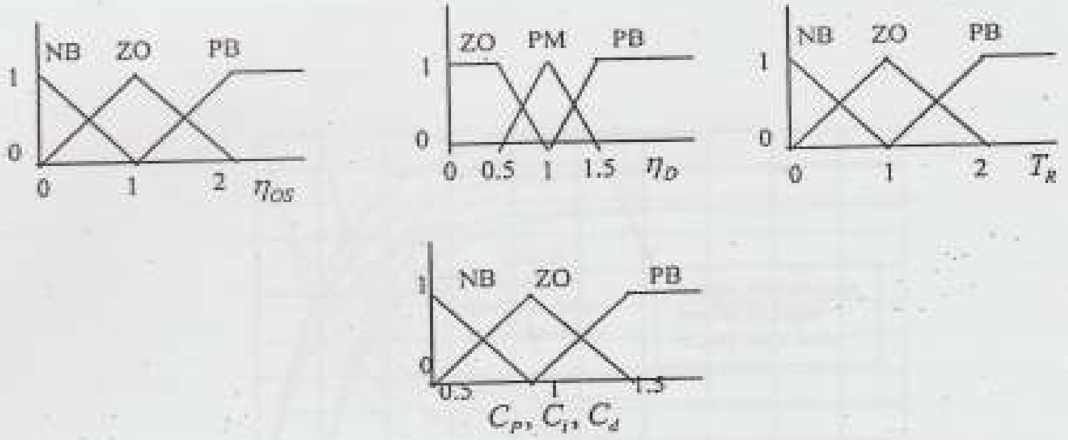


Figure 6. Membership Functions of Variables for PID Fuzzy Controller.

Quantitative values of linguistic values PB, PM, ZO, NB in table 2 are determined from a fuzzy set which is defined by the membership functions shown in Figure 6.

The format of each rule used in both direct PI fuzzy controller and PID fuzzy controller is similar to the standard fuzzy logic as follows.

(If premise than consequent)

The procedure to calculate fuzzy controller output also refers to the standard procedure as follows.

1. *Fuzzification*: calculating probability value μ(*linguistic value*) of each label of each input membership function from the measured input signal ((error $e(t)$, integral of error $\int edt$) for the Direct PI Fuzzy Controller, and (η_{OS}, η_{DR}, normalized rising time T_R) for the PID Fuzzy Controller),
2. *Fuzzy interference* (*fuzzy logic*): determining which rule is used corresponding to the fuzzy input signals, and drawing recommendation of each rule. In this study, *minimum logic* is used both to calculate the value of premise and to draw recommendation which is the value of consequent of each activated rule.
3. *Defuzzification*: calculating fuzzy controller output. In this study, center of gravity (COG) method is used in defuzzification. Center of gravity method uses the following equation.

$$u = \frac{\sum_i b_i \int \mu(i)}{\int \mu(i)} \tag{13}$$

where u denotes fuzzy output, i denotes the activated rule number, b_i and $\mu(i)$ represent value of the center of the corresponding label of output membership function and probability value of the corresponding label of output membership function.

SIMULATION RESULTS AND ANALYSIS

Simulation was conducted using Euler method with sampling time of 0.001 second. A unit step reference signal is applied and the performance of each control system is evaluated against change in dead time.

Figure 7 shows simulation result when a unit step reference is applied to the plant without any controller. The selected plants have dead time of 0.1 second and 1 second, while step like disturbance varies at {0, -0.1, -0.2}. The solid lines represent plant outputs and the broken lines express error signals between the unit step reference and the plant outputs. It can be seen that the plant without any controller leaves steady state error when there is input disturbance. More over, larger input disturbance results in larger steady state error. This result justifies the necessity of a controller which is able to improve steady state performance.

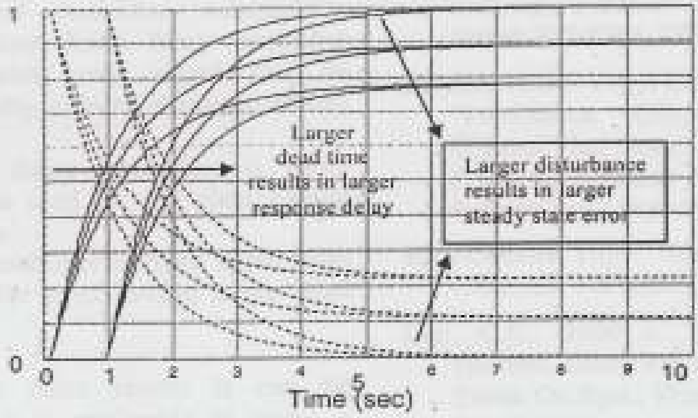
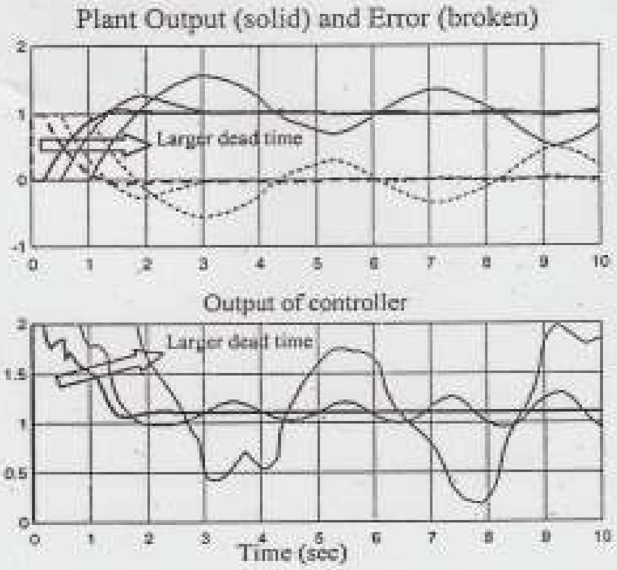


Figure 7. Step Response of the Plant Without any Controller.

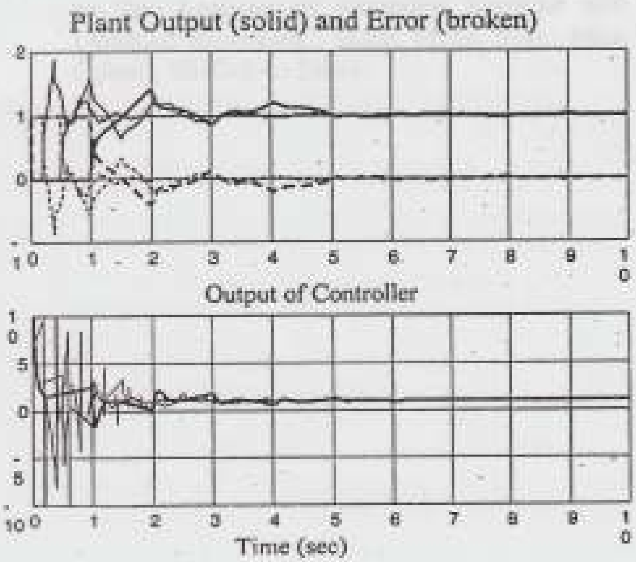
Figure 8 shows simulation results when a unit step reference is applied to a control system using the designed direct PI fuzzy controller under the effect of a step like disturbance of -0.1. The dead time is changed to {0.2, 0.5, 1.0}. In the upper figure the solid lines represent plant outputs while the broken lines represent error signals between the unit step reference and the plant outputs. The lower figure shows output signal of each corresponding direct PI fuzzy controller. The bolded lines are results when the plant has dead time of 0.2 second. It can be seen that the direct PI fuzzy controller provides better performance, in terms of steady state error and tracking performance, for a plant having smaller dead time.

Figure 9 shows simulation results of the plant with PID fuzzy controller under the effect of input disturbance of -0.1 The dead time is changed to {0.2, 0.5, 1.0}. In the upper figure the solid lines represent plant outputs while the broken lines represent error signals between the unit step reference and the plant outputs. The lower figure shows output signal of each corresponding PID fuzzy controller. The bolded lines are results when the plant has dead time of 1 second. It can be seen that the PID fuzzy controller provides better performance, in terms of steady state error and tracking performance, for a plant having larger dead time.


Plant Output (solid) and Error (broken)

Output of controller

Figure 8. Simulation Results of the Plant With Direct PI Fuzzy Controllers.


Plant Output (solid) and Error (broken)

Output of Controller

Figure 9. Simulation Results of the Plant With PID Fuzzy Controllers.

CONCLUSION AND RECOMMENDATION

From the results of this research the following conclusions can be drawn:

1. The analysis of controller mechanisms concludes that any direct fuzzy controller which incorporates error signal and its difference is hardly able to eliminate steady state error.
2. The direct PI fuzzy controller is more appropriate to be used for the plant having smaller dead time.
3. The PID fuzzy controller is more appropriate to be used for the plant having larger dead time.

Therefore, from these results it can be recommended that it is preferable to make a controller which has both the direct PI fuzzy controller mechanism and PID fuzzy controller mechanism which is equipped with a switching mechanism to automatically select the more suitable controller mechanism between the two ones according to the distance between location of the reactor and the oil heater.

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REFERENCES

Estiko Rijanto. Serpong, 2004. "Modeling and On-line Process Identification of GMS Flake Shaping Process Using RDF", Publikasi Ilmiah PPI-KIM, ISSN.0852-002X, 191/200.

Hilyati, et.al., Yogyakarta, 6-7 November 2001. "Pembuatan Gliserol Monostearat Dari Gliserol dan Asam Stearat Minyak Sawit", Prosiding Seminar Nasional X: Kimia dalam Industri dan Lingkungan, , 315/319.

Kirk-Othmer. 1999. "Surfactant", Encyclopedia of Chemical Technology, Vol.23, 512/513.

Lee. C.C., 1990 a. "Fuzzy logic in control systems: fuzzy logic controller, part I" IEEE Trans. On Syst., Man., and Cyber., Vol. SMC-20, 404/418.

Lee. C.C., 1990 b. "Fuzzy logic in control systems: fuzzy logic controller, part II", IEEE Trans. On Syst., Man., and Cyber. Vol. SMC-20, 419/43.

Mamdani, E.H. and S.Assilian. 1974. "An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller", Int. J. Man-Machine Stnd. 7-1, 1/13.

Nomura and Saito, August, 1989. "Application of Fuzzy Logic in Auto Tuning System for PID Controllers", (in Japanese), Hitachi Hyouron, 71(8).

O.J.M. Smith. 1959. "A Controller to Overcome Dead Time", ISA J., 6(2), 28/33.

Zadeh, L.A., 1973. "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes", IEEE Trans. Syst., Man Cyber., SMC-3-1, 28/44.