Optimization of PID Control Parameters with Genetic Algorithm Plus Fuzzy Logic in Stirred Tank Heater Temperature Control Process

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Abstract— **This paper describes a method to determine Proportional Integral Derivative (PID) controller parameter using Genetic Algorithm with the Fuzzy Logic controller of temperature control of Stirred Tank Heater. The system design begins with the search for the transfer function on the Stirred Tank Heater. The fuzzy logic system design is used to find the parameters in the Genetic Algorithm is the probability of crossover and the probability of mutation. This parameter is used to find the value of Kp, Ki, and Kd on the PID controller. Based on the experiment, the control system output response reaches error steady state, and overshoot are smaller when the controller is tuned with Genetic Algorithm plus Fuzzy Logic than Ziegler-Nichols method. But in term rise time and settling time, Ziegler-Nichols method is smaller than Genetic Algorithm plus Fuzzy Logic method.**

Keywords—Genetic algorithm; fuzzy logic; PID; stirred tank heater

I. Introduction

In the industrial world, the heater has an important role in the industrial process, especially chemical industry to improve process efficiency and produce good product quality [1,2]. One type of heater in the industrial world that is widely used is Stirred Tank Heater (STH). Stirred Tank Heater is a heating tank with a stirrer that is often used in chemical industry to perform batch reactions on a small scale to produce a new material. The new material is the result of the process of mixing two materials which are combined into one or only use one material in the presence of a catalyst aid so as to produce a new material as well as passed by the heating process. Therefore, the problem often faced is the temperature control on the heater. As a heater or burner in stirred tank heater, it is usually using steam or gas. Therefore, to control the temperature to reach the desired set point, then the burner must be controlled for optimal to heat the tank.

In controlling the temperature, many researchers use Proportional Integral Derivative (PID) [3], and Proportional Integral (PI) controllers. [4] Since these controllers are very popular among industry, simple, easy to implement [5]. The PID controller aims to generate an output response to a match with the desired by correcting the errors. However, the problem in this controller is the tuning of parameters if changes or interruptions occur. So, it needs an adaptive tuning parameter system. Many other researchers try to solve this problem by using controllers such as fuzzy logic type-2 [6], and Neural Network [1]. Even some researchers try to combine with other controllers to improve the performance of this PID controller for any changes or system variations [7, 8]. This combination is usually done for tuning the PID parameters adaptively as done using the genetic algorithm (GA) [9]. This Genetic Algorithm has the advantages of global optimization and robust so that GA is able to overcome the weakness of PID tuning compared with Ziegler Nichols method.

This paper will explain STH temperature control by using PID controllers where the PID is tuned with GA plus Fuzzy Logic. The designed STH is STH in laboratory scale

This paper is structured as follows: section 1 Introduction that explains the problem, current research, and objectives of this paper. Section 2 modeling Stirred Tank Heater and GA as well as Fuzzy Logic. Section 3 Research Method which describes the proposed control method in this paper. Section 4 Result and Analysis of the experiment conducted, Conclusion is the final conclusion of this paper.

II. Stirred Tank Heater control

A. Stirred Tank Heater Modeling

The STH work process begins with an input in the form of basic materials to be processed. It is then put into the tank used for the processing and mixing the basic material. In the tank, the substances in the form of basic materials will undergo a reaction process. The reaction process occurs due to heating aids. Usually, the heater in the stirred tank heater is a coil that is twisted and implanted on the inner side of the tank of stirred tank heater with steam as the source of heating. The heat generated from the steam in conduction transferred to the substances contained in the reactor tank through the coil wall. The heat which has moved from the steam to the substances contained in the tank will then be assisted with the stirrer contained in the reactor tank in order to make the heat transfer process to be uniformly in conduction. The result of the reaction process will produce a new substance at the output of the heater tank. In the experiment that has been conducted, the heater has used the

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furnace as a place of combustion and gas is used as fuel for heating sources. The position of the furnace is placed under the tank as shown in the following Fig. 1.

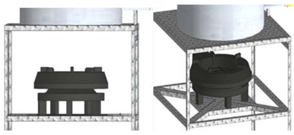

Fig. 1. Heater Design

The process of temperature control in the STH is done by conducting temperature control process (T) on the liquid contained in the tank. Assuming that the input and output flow rates coming in and out of the tank are the same. Then, the focus of the measurement is on the temperature of the liquid and the manipulated variable, the rate of heat flow, Q, provided by the furnace. Fig. 2 is a temperature control diagram for stirred tank heater.

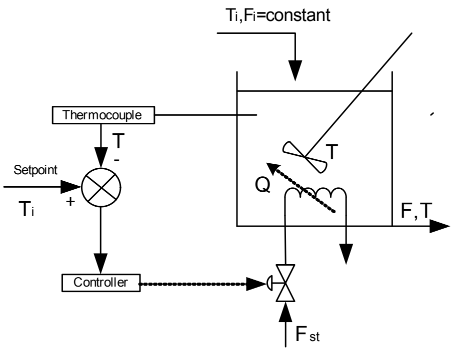

Fig. 2. Temperature control chart on Stirred Tank Heater

Assuming that the heater has been in operation for some time and the temperature of the fluid is kept constant (TS), while the fluid volume is also kept at a constant state at a value of V. It can be said that the heating operation in the stirred heater tank is steady. The mathematical equation model contained in the stirred tank heater can be defined by the law of total energy balance in the process tank by the equation:

$$V\rho C\frac{dT}{dt} = WC(T_1 - T) + Q \quad (1)$$

$$\frac{dT}{dt} = WC(T_1 - T) + Q \quad (2)$$

or

$$M_D C_D \frac{dT_D}{dt} = K_A A_A \frac{T_A - T_D}{X} - h_p A_P (T_D - T) \quad (3)$$

Where M is the mass of the tangka (kg), V is the volume of the vessel (m3), C is the heat type (KJ / KgoC), $T_{I,S}$ = steady state of the input temperature (oC), F is the fluid flow rate (m3 / s), ρ is the density of the liquid type (Kg / m3), TS = the steady state of the output temperature (oC), W = mass flow rate (W = F. ρ) (Kg / s), ρ is the density of the type (Kg / m3). By assuming the dynamic conditions in equation (3) can be ignored, it is assumed that the tank wall value of temperature (TD) equals the temperature of the burning gas (TA). So equation (3) becomes:

$$0 = K_A A_A \frac{T_A - T_D}{X} - h_p A_P (T_D - T) \quad (4)$$

Thus, it is obtained a T_D that can be substituted in equation (1) resulting in:

$$V\rho C\frac{dT}{dt} = WC(T_I) - WC(T) + UA\,(T_A - T) \quad (5)$$

Where UA can be defined as the multiplication coefficient of heat transfer (h) to the cross-sectional area (A). The UA equation is as follows:

$$UA = \frac{h_p A_p \frac{K_A A_A}{X}}{\frac{K_A A_A}{X} + h_p A_p} \quad (6)$$

If it is seen from equations (1) and (2), there is a relationship of the equation between the burned temperature with the coming out gas pressure of the supply burned gas to obtain the equation:

$$Q = UA(P_G - T) \quad (7)$$

So the dynamic equation model of stirred tank heater in equation (1) becomes:

$$V\rho C\frac{dT}{dt} = WC\,(T_I) - WC(T) + UA(P_G - T) \quad (8)$$

Because the T output variable and the T_I and P_G input variables are still nonlinear, these variables are converted into a linear form by deviating the variables. Then, it is substituted into equation (8) then the deviation equation of the variable obtained as follow:

$$V\rho C\frac{d(T - T_S)}{dt} = WC(T_I - T_{I,S}) - WC(T\text{-}T_S) + UA((P_G - P_{G,S}) - (T\text{-}T_S)) \quad (9)$$

Or $$V\rho C\frac{dT'}{dt} = WCT_I' - WCT' + UA(P_G' - T') \quad (10)$$

By doing the Laplace transform, the equation is as follows:

$$V\rho C\, sT'(s) = WCT_I'(s) - WCT'(s) + UA(P_G'(s) - T'(s)) \quad (11)$$

Based on equation (11), the temperature control of stirred tank heater can be seen in the following block diagram:

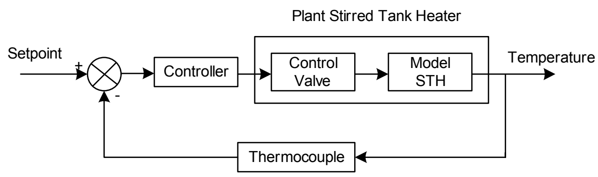

Fig 3. The block diagram of temperature control on Stirred Tank Heater

Fig. 3 illustrates that the actuator in this control system is the control valve on the heater. The control valve modeling can be approximated by using a first-order differential equation. The following equation is a common form of the control valve exchange function:

$$\frac{P_s(s)}{P(s)} = \frac{K_{cv}}{\tau_{cv}s + 1} \quad (12)$$

Where: P_s (s) represents the control valve output signal, K_{CV} states the gain of the control valve change, τ_{CV} represents the time constant of the control valve, and P (s) represents the control valve input signal.

The temperature will be detected using thermocouple which will be compared with the given setpoint value. So the controller will correct the error or the difference between the setpoint and the temperature detected from the plant.

B. PID Control Algorithm

PID controller is one of the controllers that are widely used in industry. In these controllers, the P, I and D control elements are all intended to accelerate the reaction of a system, eliminating offsets and producing large initial changes. So that any deficiencies and advantages of each controller P, I and D can cover each other. The equation of this controller is shown as in the following equation:

$$u(t) = K_P + \frac{1}{T_i}\int e(t)dt + T_d\frac{d\,e(t)}{dt} = K\left[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{d\,e(t)}{dt}\right] \quad (13)$$

From equation (13), e (t) is an error signal in t time defined as the ratio between sensor readings and determined set points. K is an amplifier. T_i is integrase time and T_d is a derivative time.The Fig.4 below is a block diagram of the PID controller:

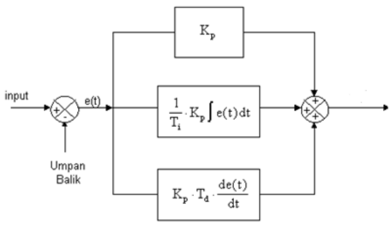

Fig. 4. PID Controller Block Diagram

C. Genetic Algorithm

Genetic Algorithm (GA) as a branch of Evolution Algorithm is a method used to solve a search value in an optimization problem, namely a problem that is not linear. The algorithm was first introduced by John Holland in 1975 based on the genetic processes in living things. In the Genetic Algorithm, the search technique is carried out simultaneously on a number of possible solutions known as the population. Individuals in one population are called as chromosomes. A chromosome is a solution that is still in form of symbol. A value that states the basic unit that forms a certain meaning in a single gene (chromosome) is called as the genotype (gene). In Genetic Algorithms, these genes can be binary, float, integer or character or combinatorial values. While the value of the gene is called the allele. The initial population is constructed randomly, while the next population is the evolution result of chromosomes through an iteration called generation. In each generation, the chromosomes will go through the evaluation process using a measuring instrument called as a fitness function. The fitness value of a chromosome will show the quality of the chromosomes in that population. The next generation is known as the offspring formed from a combination of two current-generation chromosomes acting as a parent using a crossover and mutation operators. The population of the new generation is formed by selecting the fitness value of the parent chromosome and the fitness value of the offspring, and rejecting the other chromosomes so that the population size (number of chromosomes in a population) is constant. After going through several generations, this algorithm will center on the best chromosomes.

D. Fuzzy Logic

Fuzzy Logic was introduced in 1965 by prof. Lotfi A. Zadeh from the University of California USA. In general, Fuzzy Logic is a calculating methodology with word variables (linguistic variables), instead of counting with numbers. Fuzzy Logic is a logic that has the value of vagueness or disguise between right and wrong. The differences of Fuzzy Logic with classical logic where the usual classic logic has a value of not = 0 and yes = 1 while Fuzzy Logic has the value between 0 and 1. Fuzzy Logic can be used to model various systems and solve nonlinear mapping problems. Fuzzy Logic is based on human language, can be applied in control system design without having to eliminate the conventional control system design techniques that already exist. In the Fuzzy Logic control system, there are several operational steps that include:

1) Fuzzification

Fuzzification is the process in which the input crisp value is created in the fuzzy set. To convert the input crisp into an input fuzzy, first determine the membership function of each input crisp, then fuzzification will take the input crisp and compare it with the membership function to generate the input fuzzy. In this paper, the membership function used is Gauss as shown in Fig. 5 below:

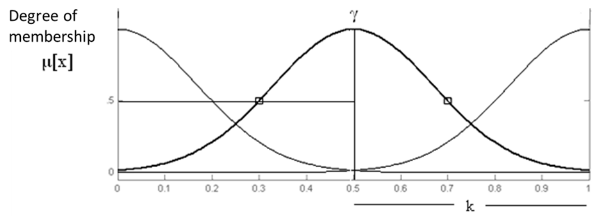

Fig 5. Representation of Membership Function Curve Gauss form

The membership function equation is:

$$G(x;k;\gamma) = e^{-k(\gamma - x)^2} \quad (14)$$

2) Fuzzy Inference of System

Inference process of the system where input value rationalization is conducted to determine the output value as a form of decision-making based on the IF-THEN rule given. The process of implication is done on each rule. The input of the implication process is the degree of truth for the antecedent and the fuzzy set in the consequent part. The implications will change the shape of the output fuzzy set resulting from consequent. Two functions that are often used in the implication process are min and max. There are several methods for the application of fuzzy systems, such as the Tsukamoto method, the Mamdani method, and the Sugeno method. The Mamdani method is the most common method to discuss fuzzy methodology. The FIS output of Mamdani type is a fuzzy set and not just an inversion of the output membership function. So, to calculate the output price of IF-THEN rule, this method should calculate the area under the fuzzy set curves in the output section. The general form of fuzzy basic rules namely:

IF (X1 is A1) • (X2 is A2) •...•(Xn is An) THEN Y is B (15)

3) *Defuzzification*

If the input of fuzzification is a single number, that is the input variable, and the output is the degree of membership in a fuzzy set in the antecedent, then the input and output of defuzzification are the inverses. The most common type of single digit is the center of area or centroid of the curve of the fuzzy set, the combinations result of all the rules into a single fuzzy set. The way to calculate this number is equal to calculate the center of mass of a closed curve. The equation of the midpoint method is as follows:

$$Z^* = \frac{\int \mu(z) z dz}{\int \mu(z) dz} \quad (16)$$

III. Research Method

This research has been developed at Control and Robotic Laboratory Electrical Engineering Department of Universitas Sriwijaya. This stirred tank heater in laboratory scale as shown in Fig. 6 using gas as its heater and temperature sensor is a thermocouple, its stirrer using DC motor. The first tank is a place to collect water and is also used as a disturbance while the second tank is a stirred tank heater, where in this second tank the temperature is maintained in a constant condition. The stirred tank heater image can be seen in Fig. 6 below:

Fig 6. Stirred Tank Heater

The Parameter data from stirred tank heater are:

TABLE I. Parameter Stirred Tank Heater Crossover

Variable	Value	Unit
Heater Tube Volume (V)	26×10^{-3}	m^3
Water Density (P_{air})	10^3	Kg/m^3
Debit (F)	0.25×10^{-3}	m^3/s
$K_{Aluminum}$	205.98	w/m°c
h_{Air}	2394.3	w/m^2 °c
UA	262.5	w/ °c
Cross-sectional area (A)	0,1104	m^2
C_P(water)	4,2	KJ/Kg°c
C_P(aluminum)	0.92	KJ/Kg°c

The block diagram of the stirred tank heater system can be seen in Fig. 7 below:

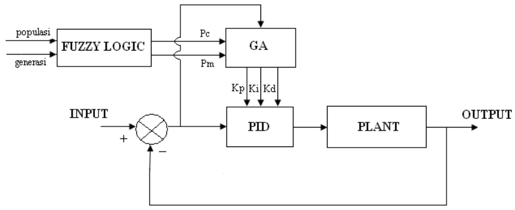

Fig. 7 Stirred Tank Heater temperature control block diagram [10]

In the block diagram, the plant is a stirred tank heater. While the controller is the PID in which the parameters of the PID (Kp, Ki, Kd) tuned with genetic algorithm (GA) using the objective function. This objective function is used to find PID control parameters that minimize overshoot and accelerate the rise time by minimizing the fitness function of error performance index and reducing steady state error with mean square error (MSE) as seen in the following equation:

$$MSE = \frac{(x_1 - x_{11})^2 + (X_2 - x_{22})^2 + \ldots + (x_n - x_{nn})^2}{n} \quad (17)$$

The MSE equation expresses the quality of the individual concerned. X represents the system reference value and output of the system. The objective function that needs to be achieved is to minimize the error generated by the plant Stirred Tank Heater, so that:

$$F_{obj} = \min (MSE) \quad (18)$$

While the probability value of crossover (Pc) and mutation probability (Pm) is obtained from the output of fuzzy logic set. The linguistic values of input variables (population and generation) and outputs (Pm and Pc) are divided into five fuzzy sets: very small, small, medium, large, and very large at intervals [0 100] with rules as shown in Table II and III .

TABLE II. RULES FOR CROSSOVER PROBABILITY VALUE

Pc / **Generasi**	**Population**				
	Very small	**Small**	**Medium**	**Large**	**Very large**
Very small	Very large	Large	Small	Large	Very small
Small	Large	Large	Large	Very small	Small
Medium	Very large	Medium	Small	Medium	Small
Large	Very large	Medium	Very large	Very small	Very small
Very large	Medium	Medium	Small	Very large	Very small

TABLE III. RULES FOR THE MUTATION PROBABILITY VALUE

Pm / **Generasi**	**Population**				
	Very small	**Small**	**Medium**	**Large**	**Very large**
Very small	Very large	Large	Medium	Very small	Very large
Small	Very large	Medium	Small	Large	Small
Medium	Large	Large	Large	Very small	Very small
Large	Medium	Medium	Small	Medium	Small
Very large	Very large	Small	Very large	Very small	Very small

The output of each rule is a fuzzy set weighted with the degree of antecedent truth and the weight of its own rule, in this case, the weight for all rules are 1. In the genetic algorithm, there are several inputs to the training process. In the fitness function, there are a number of variables. It is the number of variables that will be searched by using genetic algorithm method. In this case, the variables that will be searched are the parameters of P, I, D, and N, so the number of variables in this paper is 4. Another thing to note is Mutation and Crossover. The mutation and crossover values of the Genetic Algorithm are obtained from the fuzzy output set in the process prior to this optimization, i.e. Pc and Pm values. After entering the Pm and Pc value on mutation and crossover, then the training of Genetic Algorithm can be done directly. The results of the training will show the 4 variables sought, namely the value of Kp, Ki, Kd, and N.

IV. RESULT

In this experiment, test and simulation were conducted by using Genetic Algorithm method with the Fuzzy Logic system and compare the test result with test result if using the conventional method of Ziegler-Nichols. The test with these two methods uses the same plant Stirred Tank Heater specification. Tuning parameter of PID controller using Ziegler Nichols method got parameter value such as Kp, Ki, and Kd were 1234.17, 1.5 and 0.3564 respectively. The PID controller response is obtained by using parameter tuning using Ziegler-Nichols conventional method as shown in Fig. 8. Based on Figure 8, it appears that the steady state is faster to obtain by the Ziegler-Nichols method, but in this method, there are still many steady errors state and the overshoot generated is too high. Whereas PID controller responses are obtained by using Genetic Algorithm method plus Fuzzy Logic system can be seen in Fig. 9. The parameters used are pc was 0.628, and pm was 0.503. These parameters get PID control parameters such as Kp, Ki, Kd and N were 0.913, 0.91, 0.943 and 0.003 respectively.

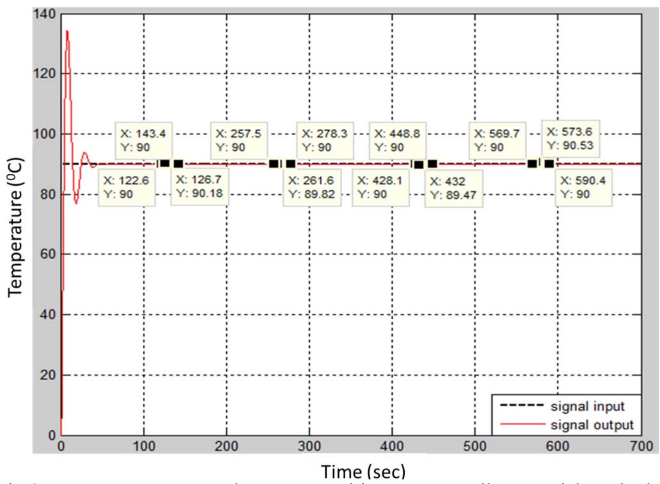

Fig.8 Temperature control response with PID controller tuned by Ziegler Nichols method

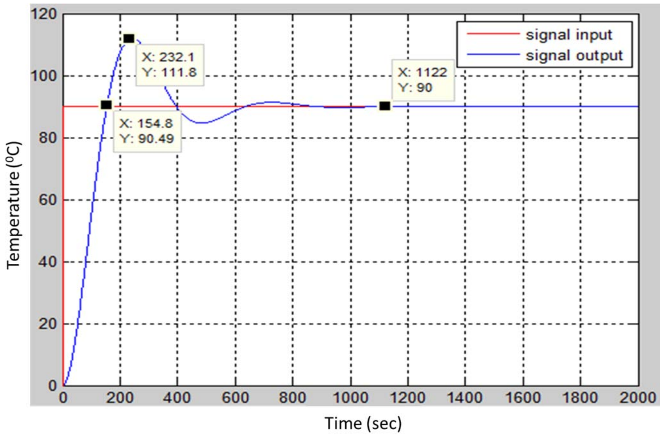

Fig 9. Temperature control response with PID controller tuned by Genetic algorithm method plus Fuzzy Logic

In Fig. 8 and 9 above, the response generated by the Stirred Tank Heater temperature control with PID that use the Ziegler-Nichols method, reaches the desired setpoint value at 90 ^{0}C faster. However, on this graph, its maximum overshoot reaches 43.9 and in this graph also still often appear steady state error. The biggest steady state error generated is 0.53. While on the graph generated using Genetic Algorithm plus Fuzzy Logic method, the steady state achieved slower than the figure 8 that is when t = 1.122 seconds. However, after the graph reaches the steady state, the steady state error does not appear and the maximal overshoot generated is only 22.1 ° C. In general, the comparison of both can be seen in table 4 below.

TABLE IV. THE GENERATED RESPON COMPARISON

Metode	*Rise Time* (sec)	*Max Overshoot* (°C)	*Settling Time* (sec)	*Error Steady state*
Ziegler-Nichols	4.401	43.9	122.6	0.53
Algoritma Genetika *plus Fuzzy Logic*	154.8	22.1	1,122	0

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CONCLUSIONS

From the comparison result of temperature control with PID that use Genetic Algorithm plus Fuzzy Logic with Ziegler-Nichols method, the rise time is achieved faster with Ziegler-Nichols method, but in Ziegler-Nichols method there are still many steady state errors and too high overshoot produced. On the other hand, if the Genetic Algorithm plus fuzzy logic used, the rise time achieved slower, but no steady state error and a very small maximum overshoot. Overall Genetic Algorithm plus fuzzy logic is better performance than Ziegler-Nichols method in temperature setting. This is seen from the resulting steady state error and small overshoot. A long time is needed for Genetic Algorithm plus fuzzy logic in the process to get PID control parameters. But in the temperature control, the time to reach the setpoint is also long enough so that long time on Genetic Algorithm plus fuzzy logic method is still acceptable. Further research will be done by adding disturbance to this system.

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