J. Appl. Environ. Biol. Sci., 7(4S)28-33, 2017

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Comparison Effectiveness of PID, Self-Tuning and Fuzzy Logic Controller in Heat Exchanger

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Received: April9, 2017
Accepted: June 16,2017

ABSTRACT

The objective of this study is to find the most effective controller among three types of controller which were Proportional Integral and Derivative (PID), Self-tuning and Fuzzy logic controller. PID controller represent linear controller, while Self-tuning controller (STC) and Fuzzy Logic controller (FLC) represent non-linear controller. The controllers were applied in heat exchanger system. Heat exchanger system was chosen because the system need close monitoring in order to get the best performance. The parameters involved in heat exchanger such as temperature differences, surface area and flow rate of the fluid are important to be controlled. Due to that, a controller was used to keep the process in control so that it will not deviate from the set point. In this study, the heat exchanger system was simulated using MATLAB Simulink as the main system to run the simulation. Overshoot on the controller graph, settling time and integral absolute error (IAE) were three criteria that had been considered to measure the effectiveness of the applied controller. From the result obtained, PID controller have fastest settling time to achieve set point which is 120s. However, this controller has overshoot which is 44% and have the highest IAE which is 8.6125. Apart from that, fuzzy logic and self-tuning controller had almost same settling time and IAE value. Both controllers are a non-linear control system. The presence of disturbance does not give major changes where overshoot problem was eliminated and have medium fast response obtained. For this case, the fuzzy logic faster approximately 5s as compared to STC.

KEYWORDS: PID Controllers, Fuzzy Logic Controller (FLC), Self-Tuning Controller (STC).

INTRODUCTION

It is known in many industries including manufacturing and service industries that there are lots of effort needs to be done in order to keep the process control to not deviate from the initial set up. The most crucial issues to be played are about improving the process productivity, and at the same time to increase the quality of the products. Certainly several years back, there are many efforts taken by engineers and researchers to keep both of these important issues in hands.

One of the methods to overcome this problem is to invent controller. They are many type controller that was invent by researcher such as is Proportional Integral and Derivative (PID) controller, Fuzzy logic controller, Self-Tuning Controller (STC) and many more. Each controller has different method to monitor, tracking major change and adjusting the variable so that the output is consistent towards the set point.

In real industries, a lot of companies prefer to use shell and tube exchanger for heating system. It is because of this type heat exchanger have big size which make it able to sustain extensive pressure and heat [1]. Thus, it will make it much more durable to be used in long duration of time. Other than that, inside heat exchanger also can be custom made and it will depends on condition required such as easy to clean, to sustain the pressure and temperatures used in operation, to maintain the level of corrosion, to accommodate high asymmetric flows and many more [2].

Example for heat exchanger working is, hot steam will enter the heat exchanger while cold fluid will enter at opposite direction. It will have barrier between steam and cold fluid usually use pipe to make sure the fluid not contact each other and it just have heat transfer. When the flow of water increased, the heat transfer between steam and cold fluid will be less, so it is required to open the valve more to give extra steam entering to the pipe. Because of that, function of controller is important in order to regulate the temperature to achieve the set point. The way controller work is measured the error from feedback data, make decision and it sent to the final control element to make adjustment either want to open or close valve [2]. The step for control system is shown in Figure 1.

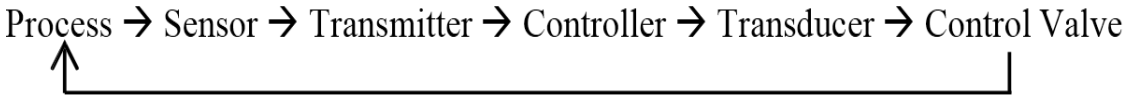

Figure 1: Control system of shell and tube heat exchanger [8]

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A temperature sensor is used in the feedback path of the control architecture as the sensing elements. The thermocouple will measure the temperature of particular outgoing fluid and the output from the thermocouple is collected and sent to the transmitter unit in the system. The transmitter will change the output from the thermocouple into a standardize signal. The standardize signal will be given to the controller unit whereas it will implements certain control algorithm, link output with setting in the set point and finally gives appropriate command towards the final control element through the actuator unit of the system. The function of the actuator unit is to convert the current unit into pressure and the final control unit will decide the amount of air required to open the valve. As a result, the valve will actuates accordingly as the decision by the controller [3].

PID controller was first developed as govern device use to regulate the speed of machine and it becomes the most popular controller that is used in industry. Control loop feedback mechanism is usually use in PID controller because it is simple and easy to handle. A PID controller have responsible to measure process variable and attempts to minimize the error by adjusting manipulated variable and give signal to final control element to take the action. However, control loop feedback has some weakness such as it take longer time to make adjustment because it just makes decision based on feedback data. In other to tackle this problem, other type of control strategies such as feed-forward, feedback feed-forward, cascade and many more was introduce [4].

Fuzzy logic controller is a way that computer make decision like human. It was first invent by brilliant Lotfi A. Zadeh in year 1965. After that, it was elaborated and implemented in industrial application. First application fuzzy logic in industrial is in cement kiln build in Denmark in year 1975. Decision of fuzzy logic can be made by combination of fuzzy set and fuzzy rule that act as a model. Fuzzy set have responsible to collect information with different degree. This information will be combined with fuzzy rule so that it can make the best decision out of it. Fuzzy rule works by using inference process which will use parts of true fact and discover the degree of their true. After that, another fact will be made that will make it true to the particular degree [4].

Self-tuning regulator was invented to deal with constant process however it have unknown parameter. It was used same procedure to deal with disturbance which is expectation, measurement, analysis and action. First analysis about direct self-tuning controller was run by [5]. There are a lot of type algorithm that are used to estimate process model such as least square, extended and generalized least square, stochastic approximation, Instrument variable, maximum likelihood and many more. This algorithm was invented to overcome the problem or weakness from each of the algorithm.

In real industries, most of the heat exchanger is used PID controller while there are have some weakness. So, in this paper, effectiveness of linear and non-linear controller is compared to determine the most effective controller when applied in heat exchanger. This paper consists of four different sections including the introduction. The introduction is introduced in the first part of the paper. Next, methodology is presented in next section. While in section three, the simulation results and discussion for different controllers and the best controllers are identified and provided. The paper is concluded in the fourth section.

METHODOLOGY

Heat exchanger system was set up in MATLAB Simulink based on available experimental data. The mathematical model [1] and transfer function were two important data to be obtained before the system can be set up. Then, the system was run without the presence of controller and with the presence of controller. Three types of controller were applied which were PID, STC and FLC. Then, the results were compared. Figure 2 shows the basic feedback control scheme in heat exchanger [3]. Set point one is set up for heat exchanger process and the controller is to compare the output with the set point and give the necessary command to the final control element via the actuator unit. Valve is needed to open or close the system so that the process going towards its set point. However, the disturbances are applied in this study which are the input flow variations and input fluid temperature variations. Three types of controller applied which are PID, self-tuning and fuzzy logic controller are to cater the variations. Sensor will detect the changes happen when the system run. Common condition that need be constant parameters were no changes happen in the level fluid of heat exchanger and capacity of the heat storage was considered negligible.

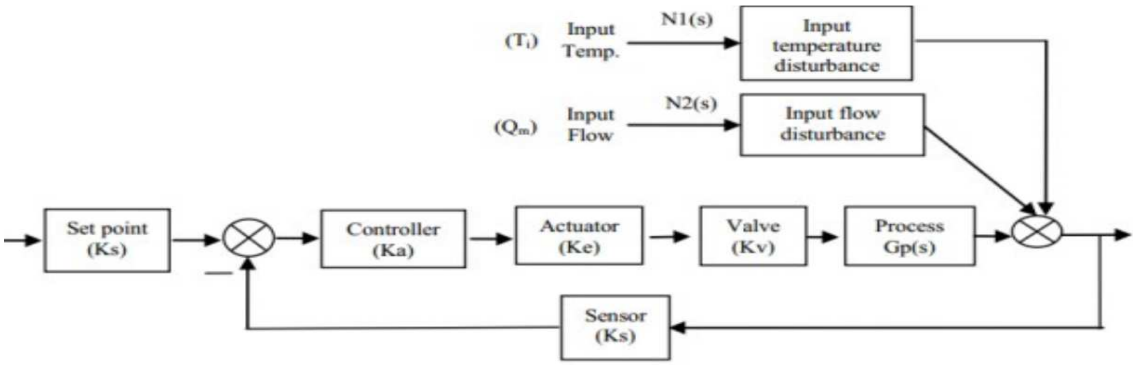

Figure 2: Basic feedback control scheme in heat exchanger [2]

The PID controller was tuned based on Ziegler Nichols formula. The fuzzy controllers with two input variables, error and rate of error variable (i.e.) the hot water flow rate to the shell side are designed. The linear membership function for both inputs and outputs was used are mamdani based fuzzy inference system. For the fuzzy logic controller, the input variable are error (e), rate of error (Δe) and the output variable is controller output (Δy). Triangular membership functions are used for input variables and the output variable. Range that are used in MATLAB to generating the membership function is Error = [-13 13], Rate = [-4 4], Variable = [-5 5] [4]. The self- tuning controller was set up based on data available from Thomas Bata University website and Ziegler-Nichols method was applied. Figure 3, 4 and 5 show the PID controller, FLC and STC system block diagram which is simulated in Simulink MATLAB.

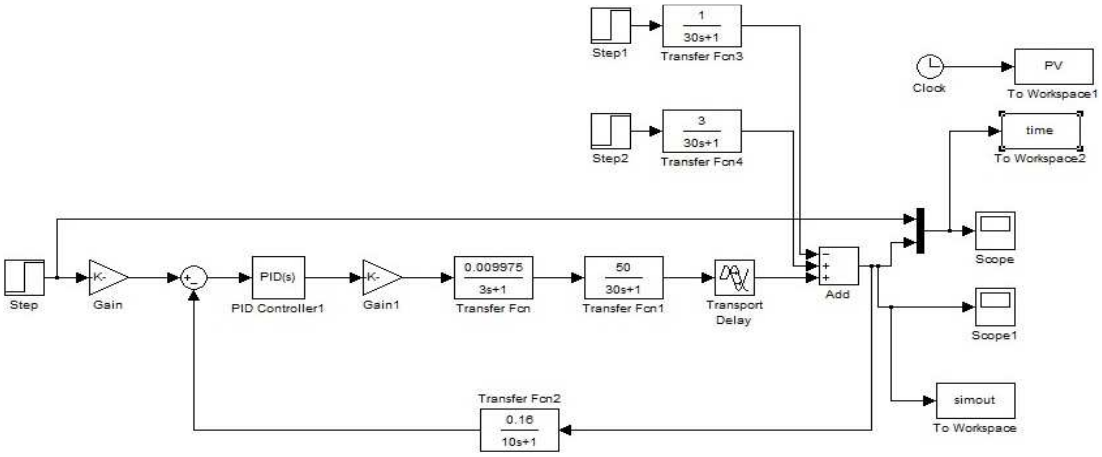

Figure 3: PID controller

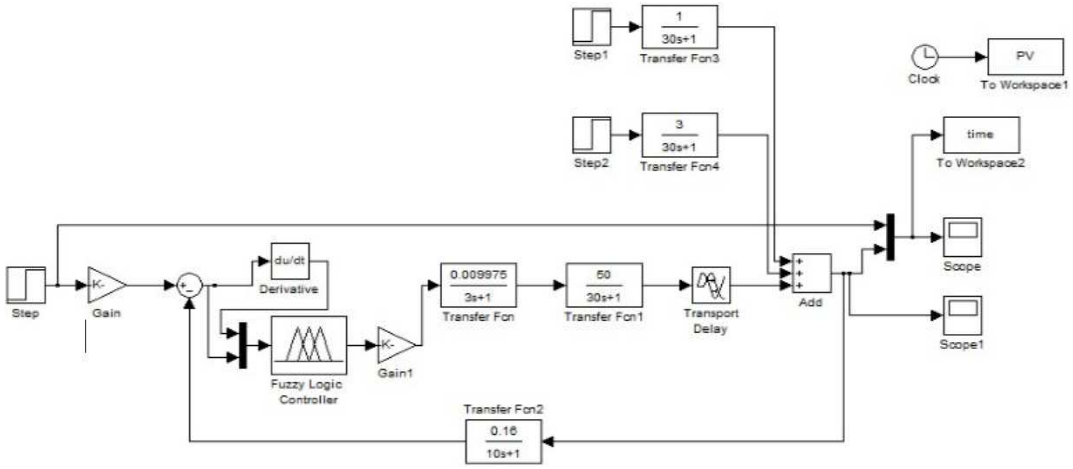

Figure 4: Fuzzy logic controller

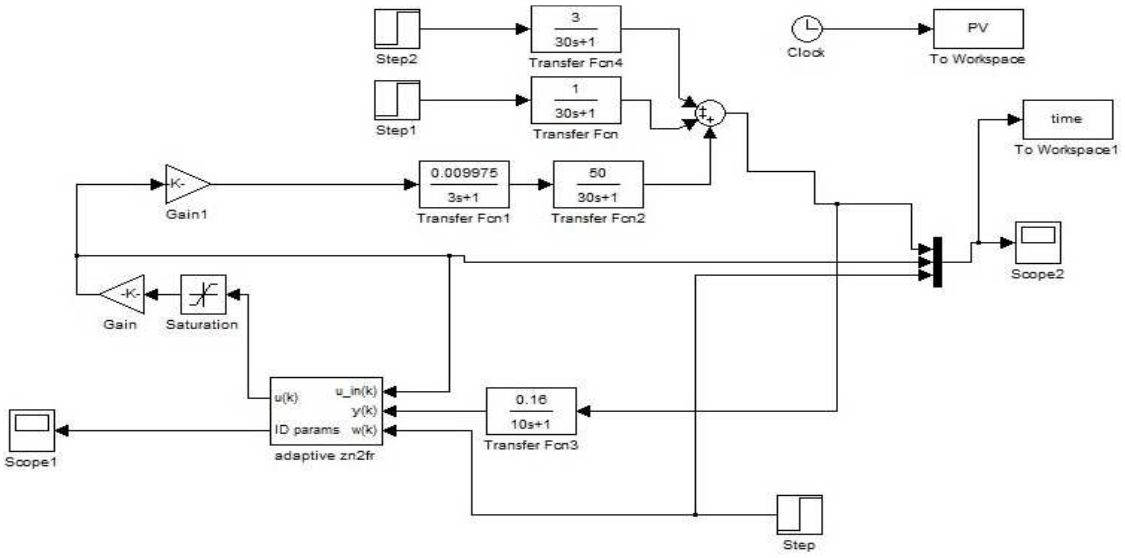

Figure 5: Self tuning controller

RESULTS AND DISCUSSION

Figure 6 and 7 show step response for PID while Figure 8 and 9 show step response for FLC and STC system, where x axis represent time and y axis represent as a set point. The aim for the controller is to obtain fast responses and good stability. Unfortunately, in real situation these two objectives are difficult to obtain simultaneously. In other word, it may be able to achieve faster response but worse stability or better stability but slower response. For the best of the control system, it is better to have the stability and medium fastness response [5]. Three important criteria to compare the effectiveness of controller are by detecting the overshoot of the controller on the graph, by observing the settling time and by calculating the integral absolute error.

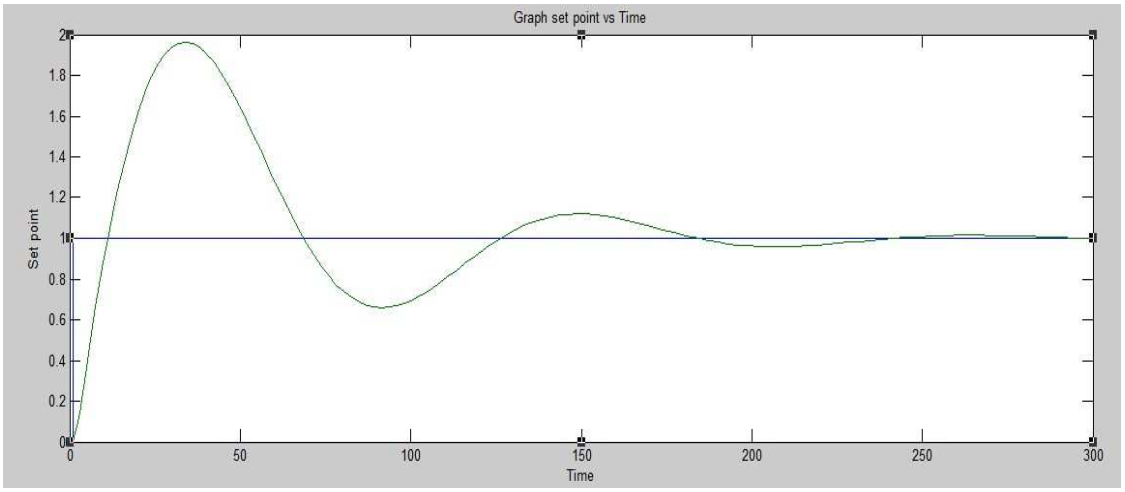

Figure 6: Result of PID controller tune by using Ziegler Nichols method

Overshoot is the maximum peak on the graph, settling time is the time for the controller to achieve stability and integral absolute error is total area under the graph. Figure 6 shows the simulation result which the PID value were obtained by using Ziegler Nichols method (P = 23.8, I = 1.65 and D = 85.442). Figure 6 shows the poor stability and worse response. Therefore, the process faced fine tuning to achieve better stability and medium fast response by changing the value of P, I and D. The process will shift to the right when P value is increased while decreasing the I value will make the process response heading faster towards to the set point and lastly increase in D will speed up the process rate [6]. The value of new PID is P = 28.8, I = 0.99 and D = 113.5 and the process response was shown in Figure 7.

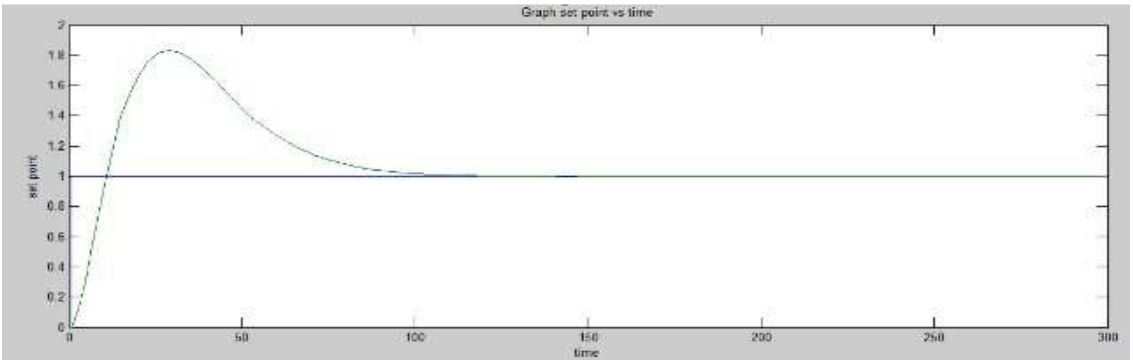

Figure 7: Result of PID controller after adjustment

Set point test were conducted to ensure all controller applied to system are working properly by changing the current set point of one into a new set point which is two. Two conditions to be observed whether the process response will move to the new set point (meaning that the controller is fully function) or not (meaning that certain flaws occur in the coding controller. Figure 10 shows that PID, FLC and STC controller able to make the process move to new set point and this ensure the process work properly.

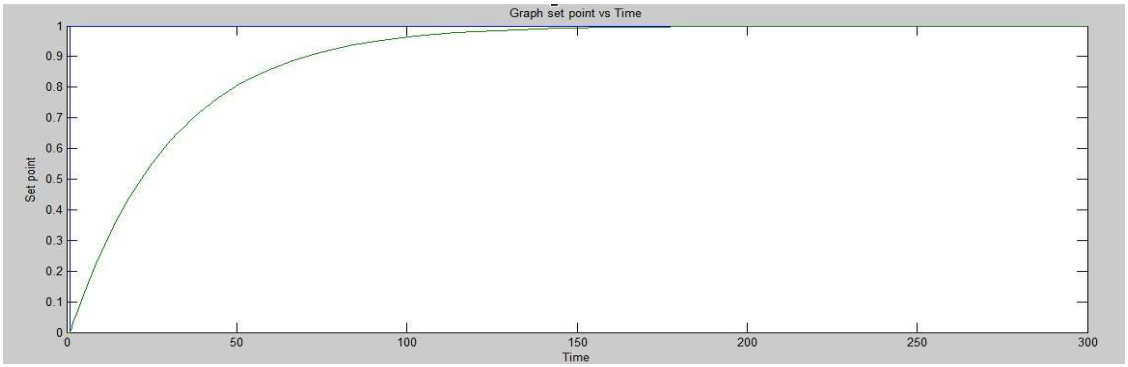

Figure 8: Result of fuzzy logic controller

Table 1 represents summarize data from Figure 7, 8 and 9. PID controller has faster settling time to achieve set point which is 120s. However, this controller has overshoot which is 44% and has the highest IAE which is 8.6125. From Figure 10, 44% overshoot at the beginning and the process move to set point at settling time 120s. The present of overshoot is due to presence of disturbance. Traditional PID controller is a linear control system due to strong disturbance, presence dead time as well as time varies parameter in the process [4]. Other researcher also assuming that PID controller is a linear control system since it creates lots of disturbances [7] and having oscillatory response and also large settling time [1]. Apart from that, fuzzy logic and self-tuning controller had almost same settling time and IAE value. Both controllers have a non-linear control system. The presence of disturbance does not give major changes where overshoot problem was eliminated and have medium fast response obtained. For this case, the fuzzy logic faster approximately 5s as compared to STC.

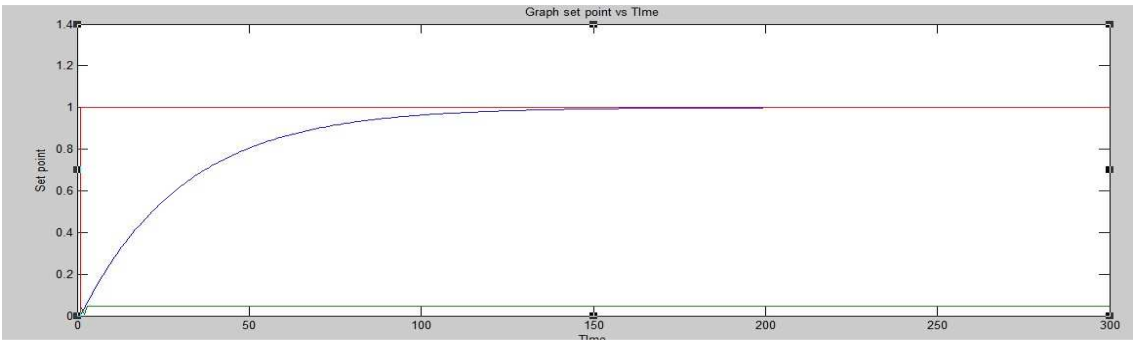

Figure 9: Result of self-tuning controller

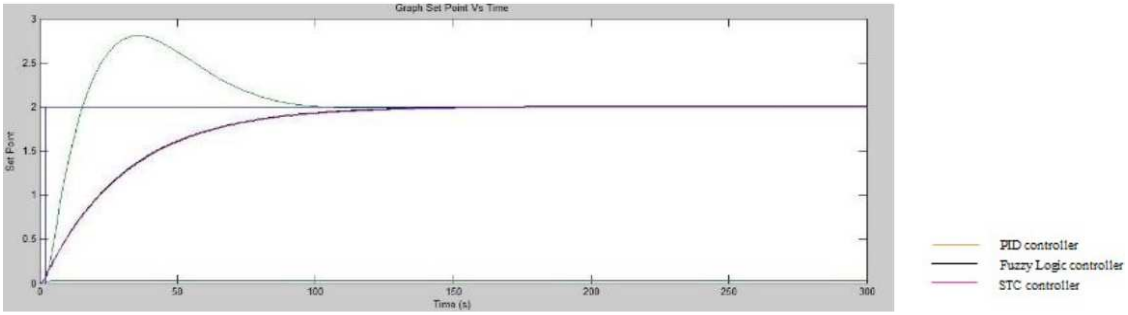

Figure 10: Result of set point test of all controller

Table 1: Summary of 3 different controllers

Control System	Maximum Overshoot (%)	Settling Time (s)	Internal absolute error (IAE)
PID	44	120	8.6125
Fuzzy logic	0	150	5.3
Self- tuning	0	155	5.28

The presence of FLC will overcome the presence of disturbance and will never overshoot because the control system itself is a non-linear control system, and it able to face flexible changes that occur in the system due to present of disturbance [4]. Same results performed by STC controller which able to overcome the disturbance, but the STC require tuning and control function at the same time and STC need to learn how disturbance react to make process deviate from set point [9].

CONCLUSION

This research comparing three types of controller to find the most effective controller that should be applied in heat exchanger system and the simulation conducted in Simulink MATLAB software. The main purpose of this project is to find most suitable controller between this three types of controller to be applied in heat exchanger. All of the controller was studied and stimulate in Simulink. From the result obtain, PID controller show the worse result, as it is categorized as a linear control system due to presence of overshoot when apply disturbance. Due to the fact that heat exchanger is a non-linear system, PID controller is not suitable to be used in this system. From literature, a non-linear control system represented by fuzzy logic controller and self-tuning controller is a non-linear control system because it can overcome the disturbance and make flexible change. Both of the controllers have shown magnificent result. In conclusion, as long as it is a non-linear control system, it can be applied in heat exchanger because heat exchanger is a non-linear system.

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