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## Design Of Temperature System On The Electrical Tank Heater Using PLC

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### Abstract

A temperature control system is required in any situation that requires a certain temperature to remain stable. Likewise, in the electrical process tank heater that requires a control system, because the temperature is not by the set value will cause overheating, causing the product temperature is not as desired and can even cause a dangerous explosion. In this project, the design is carried out temperature control on the prototype electrical tank heater using PLC Nano V5.2 as the controller, and the control method used is fuzzy Sugeno. Fuzzy logic has a value of obscurity between right and wrong and control systems. Membership value may vary from 0 to 1. This means a situation can have two values, "yes or no" and "right or wrong", so it seems as if there is a "gray" area. Fuzzy Sugeno is a fuzzy inference method for the conditions represented in the form of IF-THEN, where the system output is not a fuzzy set but a constant form. Test results on the prototype confirm that the system control with PLC as controller and fuzzy as control method has a good ability to adapt the time needed to take longer to reach a stable state at higher temperatures (33.5°C to 37°C). Then at lower temperatures (29°C to 33.5°C). Haiwell-capable interfaces change set values, display real-time graphs, and send commands to set PWM.

### Keywords:

Electrical tank heater, temperature, PLC.

## 1 Introduction

A temperature control system is required in any situation that requires a specific temperature to remain stable, like the petro industry, chemical, power, food, and other industries. For precise control, automatic systems and appropriate temperature measurement methods must be used to reduce costs, waste, and safety, especially. When dealing with a potentially dangerous process, to achieve that result well, it is necessary to control the heating process in the heating vessel properly because temperature, pressure, and volume are interrelated. The higher the temperature in the boiler at the same volume, the higher the pressure. If heating continues, if it is increased, it will overheat, and a dangerous explosion can occur. This could result in loss of life or other material losses. So, therefore, the temperature must be controlled to produce optimal products [1]. Many processes must be done to achieve products conforming to standards, such as maintaining pressure, flow, temperature, and levels under proper control [2]. The automatic control process involves measurement, calculation, comparison, and correction [3].

Temperature control on the tank heater is often used to maintain temperature. Because frequent changes and disturbances in the parameters occur during the heating process, the variable temperature used in the tank must be maintained. Overcoming these problems requires a system temperature control in the tank heater [4]. The tank heater works on the principle that heat generated from combustion fuel is channeled through a metal gasket, and then transferred to the deep water tank through convection, so the water temperature has increased. Electric tank heaters, on the other hand, are devices that use electricity as a heat exchanger's main source of energy for heating water. This type of heater uses a tank (vessel) as a container for water, which is then heated through the process of convection [5].

Proportional Integral Derivative (PID) and fuzzy logic control systems can produce a good and reliable controller response to control plants in various industries and are still widely used today. In this research, we will examine the comparison of performance indicators for PID control and fuzzy logic control based on Programmable Logic Control (PLC) on a second-order plant simulator [6]. One way that we can use to control the temperature is by using a Proportional-Integral-Derivative (PID) control algorithm system [7]. The use of this system has achieved many successes, even though it is quite challenging to do the control system because PID has a shortage at the time there is a change in parameters that are too large in the system, the PID is unable to maintain the desired temperature criteria [8]. Because temperature changes are difficult to control, it is necessary to develop a control system through software as controlling criteria by using fuzzy logic [9][10]. Fuzzy logic feels right and is used because it is a way to map an input space into an output space, has a continuous value, and fuzzy logic has a tolerance for inaccurate data [11][12].

With the problems above, this study aims to design a heater control system using the fuzzy controller method via implementation of the control system in the heater system plant so that it is expected interference with the heater can be overcome and can maintain the desired temperature [13].

## 2 Plant Design

### 2.1 Prototype Design

A heater is a form of heat exchanger that plays a role in the heating process. There are also options for alternative energy sources that can be used to heat water, such as gas, solar energy, and geothermal, as well as various sources of other energy. In the industrial sector, heaters can be used for various functions, such as dryers, air conditioners, and liquid heaters.

The prototype design made by the author is to control the temperature in the fluid with the control method using fuzzy logic control. Outside PLC controller. The fuzzy logic control method is used by the author because FLC is a control system that has a continuous value, and fuzzy logic has a tolerance for inaccurate data and there are two parameters in fuzzy control input parameters and output parameters. The input parameter is an error value from the comparison between PV-SV, for parameters output in the form of temperature results, namely cold, warm, and hot. Research that has been designed and built includes hardware and software, where hardware is in the form of Outside PLC that is connected to AC pumps, DC pumps, heaters, RTD sensors, and temperature transmitters, while the software uses Outside SCADA and HMI Haiwell Scada Cloud Develop as monitoring and controlling the process that will be going on.

The initial step of the process starts from the inlet tank, which is located under the table. Water on the inlet tank will be pumped by the pump to the heater to be heated together the product temperature according to the desired set point (Fig. 1). The RTD PT100 sensor measures the temperature in the heater process. Then will be configured by the temperature transmitter to be a

standard signal of 4-20 mA, the process variable from the temperature transmitter will be compared with the set point become the input signal for the PLC so that the error value is obtained. Then the controller will manipulate data with fuzzy calculations and generate output signals to give commands to the SSR to increase or decrease the voltage on the heating element so that the temperature in the heater can change. On the elements, the heater will convert electrical energy into heat energy to heat the liquid that is on the heater to the desired temperature. When the temperature reaches the desired set point, the SSR will remain on to keep the temperature at a liquid can maintain the desired temperature during the running process. Channel this will continue continuously so that the temperature on the heater remains at the desired set value.

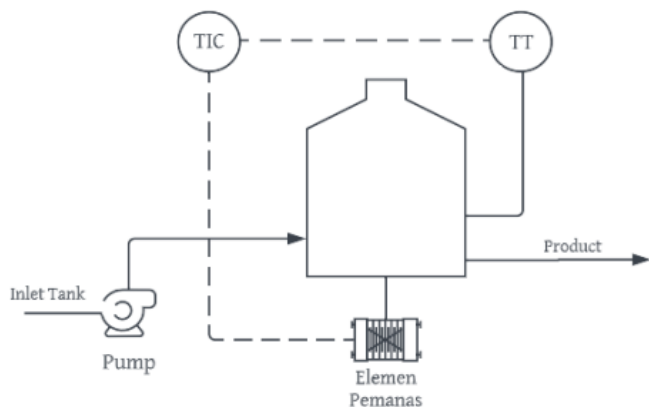


Fig. 1. P & ID temperature control system.

Fig. 2 is an image of a prototype temperature control system on electrical tank heaters. The process will begin with the turning on of pump two which will transfer the water in the feed tank to the electrical tank heater tank, later heated to the temperature that is cooled by the heater then will be transferred by pump 1 to a process requiring high heat. The water temperature will decrease because the heat calories have been absorbed by other processes. The output from other processes will be accommodated in the feed tank and will be transferred back by pump 2 to the electrical tank heater to be heated. During the process, pumps 1 and 2 will continue to run because the water used is likened to oil. Where in the process of heating, the oil is not may be heated in a stationary system as this will result in oxidation and becoming vapor or gas, which can trigger an explosion.



Fig. 2. Prototype temperature control system.

Fig. 3 is a wiring diagram of the electrical tank heater temperature control system. The installation of component wiring must adhere to the specified design. Errors in the wiring system might lead to malfunctioning components. In the electrical tank heater prototype, the PLC Outsell Nano V5.2 serves as the principal controller. PLC Outsell Nano V5.2 functions to provide

a signal to the Nano V5.2 module driver for driving an immersion heater (heating element) and to receive PV signals from the output of the weight transmitter. The Outsell Nano V5.2 PLC interfaces with a PC running the Haiwell Cloud Scada Develop program through a USB cable via the Modbus RTU protocol. The master will be Haiwell Scada Cloud Develop, and the slave will be PLC Outsell Nano V5.2 [14]. Haiwell Cloud Scada Develop can not only monitor PLC Outsell Nano V5.2 but also issue commands to it [15].

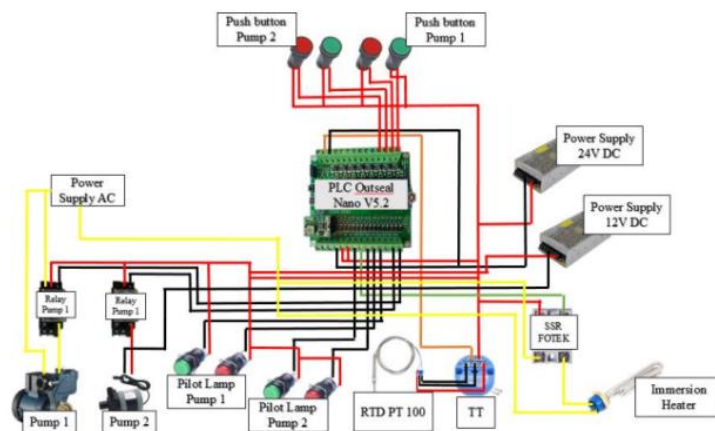


Fig. 3. Wiring diagram.

In the prototype design, there are software used, namely Matlab, Outsell Studio version V.3.6 beta 2, and Haiwell ClaudeScada version [3.36.6.2]. Matlab is used to design the fuzzy system used in temperature control by inputting the input variable that will produce the output variable. Software Outsell Studio V.3.6. beta two was used to design the ladder control system diagram with a Programmable Logic Controller (PLC). Ladder program the diagram in the Outsell Studio is a component of the control and monitoring system temperature. These components include temperature sensors, AC pump, DC pump, SSR, heater, and also LED and push button.

Haiwell Cloud Scada software is used to create software interfaces for temperature control systems, communicated via USB port cable to connect to the Outsell PLC hardware. HMI design on Haiwell Cloud Scada begins with designing the components that will be displayed, such as response graphs of process variables, set values, and manipulated variables, and for viewing the history of the chart on the historical trend by entering the time desired, to view historical data, as shown at the trend table. As for the instructions for auto and manual control on HMI. There are two switches on (green) and off (off) to turn on pump one and pump 2, as well as other hardware components.

## 2.2 PLC Outsell Nano V5.2

This research utilizes two applications, namely Outsell Studio and Haiwell Cloud Scada Develop. PLC Outsell Nano V5.2 used an Atmega 328P CPU as the CPU and is equipped with an optibot type Bootloader that already follows the IEC 61131-standard 2 Digital input PLC Nano V5.2 uses an optocoupler and Digital output in the form of NPN transistors with current regulation to avoid causing problems when overloaded or a short circuit occurs, for Outsell Nano V5.2 PLC programming using Outsell Studio software. This Outsell Studio software is in the form of an application whose data is run on a laptop or a PC in the form of a visual programming ladder diagram (a ladder diagram). Sending the program to the PLC hardware can be done via a USB cable.

## 2.3 Resistance Temperature Detector (RTD) PT100 and Temperature Transmitter

RTD PT100 is a temperature sensor whose measurement uses the principle change in resistance or electrical resistance of the metal affected by the change in temperature. The PT100 sensor is made of platinum and has three wires for this type of sensor most

commonly used in industry. RTD 3 wires measured by bridge whetstone to charge the conductor. For the principle of itswork, when the temperature element RTD increases, the element resistance will also increase. In other words, the temperature rise of the metal, which is an RTD-resistive element, is proportional to the resistance. RTD elements are usually characterized by resistance in ohms at 0 degrees Celsius (0°C). The most common RTD specifications are 100 Ω (RTD PT100), which means that the RTD element must have a resistance value of 100 at 0°C. In the prototype design for temperature measurements used, sensors RTD PT100 and temperature transmitter were used to convert quantities resistance into a current signal of 4–20 mA so that it can be processed by Outsel Nano V5.2 PLC[16].

## 2.4 Immersion Heater

An immersion heater is a heating device used to heat water or other liquid by placing the heating element into the liquid[5]. This appliance consists of a heating element that is protected by tube corrosion and heat resistance, as well as power cables connected to power sources. Method immersion heater work is very simple. When the heating element is turned on, current electricity will flow through the element and produce heat. That's heat generated by the heating element will be transferred to the surrounding liquid, resulting in the temperature the liquid will increase.

## 2.5 SSR Fotek 40DA

The Fotek 40 DA SSR is a type of Solid State Relay (SSR) from the Fotek brand with power 40A. This SSR is used to control power flow up to 40A on a single load. Fotek SSR consists of three main parts, namely input, output, and semiconductor controller. The input is a control signal (such as signal DC or AC) supplied to the Fotek SSR to control the switch. Outputs are the electric signal's issued by the Fotek SSR to control the flow of electricity on loads such as motors, lights, or other electrical equipment. SSR Fotek 40 DA uses a controlling semiconductor in the form of a TRIAC, which has speed Switching is fast and can control the flow of electricity on a single load independently and efficiently.

## 2.6 Power Supply

A power supply or power source is an electronic device that serves to change the voltage from the main power source (AC or DC) into a voltage according to the needs of electronic equipment. The prototype of the temperature control system on the electric tank heater is of the power type the supply used is the AC–DC power supply: changing the AC voltage into DC with a stable current and voltage. There are two power supplies used in this prototype the first 12V DC power supply (20 A) and the second 23 power supply 24V DC (5A).

## 2.7 Haiwell Scada Cloud Develop

Scada is a system that allows users or operators to monitor (supervision), control (control) as well as data acquisition (retrieval and recording of data)[17]. This system includes data transfer between a central Scada computer and several Remote Terminal Units (RTUs) or Programmable Logic Controllers (PLC). Scada has four main components sensors, communication networks, Remote Terminal Units (RTUs), and Master Terminal Units (MTU). Haiwell Cloud Scada Develop is a NET-based framework industrial automation monitoring and management platform developed by Xiamen Haiwell Technology Co., Ltd. Haiwell Cloud Scada Develop can directly communicate with Outseal PLC as an interface via USB cable with RTU Modbus communication protocol. Modbus is a communication protocol published by Modicon in 1979. This communication protocol was created for applied to PLCs. This communication protocol has become the de facto standard in the industry and now Modbus is the most common two-way communication and is often used as a

link between electronic media and computers. Haiwell Cloud Scada can monitor as well as give commands to PLC Outseal[18].

## 2.8 Fuzzy Control Implementation

### 2.8.1 Fuzzifikasi

In the process of controlling this temperature, there is one input that is used, namely error. The error value is obtained from a comparison of the reading values from the RTD sensor (process variable) with the desired set value. For more details as shown in Fig.4.



Fig. 4. Fuzzy designer.

Table 1 contains the membership function values for fuzzy input, where membership is divided into three parts, namely Negative, Zero, and Positive for error. More clearly as shown in Fig.5.

Table 1. Membership function input fuzzy

Name	Type	Parameters
Negatif	Trimf	-15 -5 0
Zero	Trimf	-10 0 10
Positif	Trimf	0 5 15

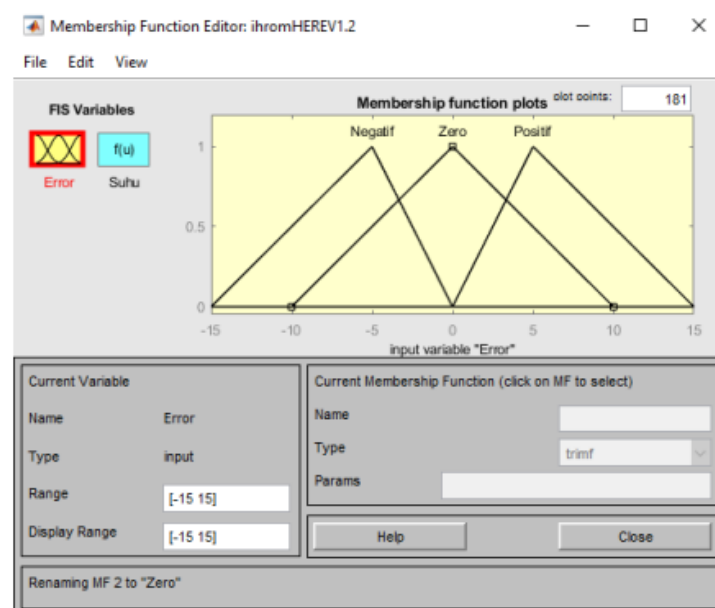


Fig. 5. Membership function error.

Then there is a fuzzy output value, namely the temperature, which is divided into three parts namely Hot, Warm, and Cold. Each of these sections has its parameter values, as shown in Table 2. And more clearly as shown in Fig.6.

Table 2. Membership function output

Name	Type	Parameters
Cold	Constant	-1000
Warm	Constant	250
Hot	Constant	1000

### 2.8.2 Rule Base Design

The fuzzy rule base is part of the designed fuzzy system, where the function is to get a value based on the level of truth. Fuzzy design logic as shown in Fig.7, for the design of the fuzzy logic rule base controllers as follows:

1. If (Error is Negative) then (Temperature is Hot)

- If (Error is Zero) then (Temperature is Warm)
- If (Error is Positive) then (Temperature is Cold)

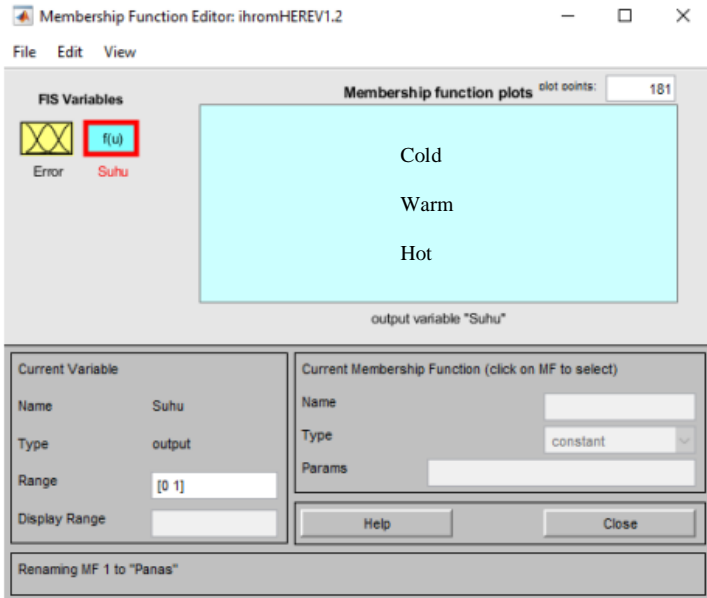


Fig. 6. Membership function output.

Setting the rule base system is done using Matlab on the menu rule editor, and the output variables from the rule base as shown through the rules viewers.

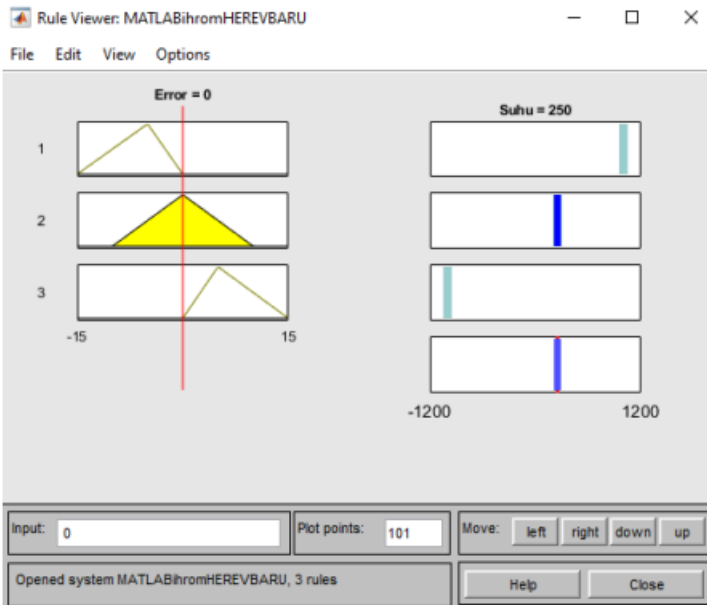


Fig. 7. Rule base viewer.

### 2.8.3 Fuzzy Inference System

After designing the fuzzy rule base, the next step is to do manual calculations using the zero-order Sugeno method with if-then rules. An example of a calculation performed with an Error value of -7, 0, and 7 for calculation is:

[R1]:If(Error is Negatif) then (Temperature is Hot)

$$\begin{aligned} \text{apredikat1} &= \mu_{\text{Negatif}}(-7) \\ &= \min(\mu_{\text{Negatif}}(-7)) \\ &= \min(0.3; 0.8) \\ \mu_1 &= 0.3 \\ Z_1 &= 795 \end{aligned}$$

[R1]:If(Error is Zero) then (Temperature is Warm)

$$\begin{aligned} \text{apredikat2} &= \mu_{\text{Zero}}(0) \\ &= \min(\mu_{\text{Zero}}(0)) \\ &= \min(0.5; 0.5) \end{aligned}$$

$$\mu_1 = 0.5$$

$$Z_1 = 250$$

[R1]:If(Error is Positif) then (Temperature is Cold)

$$\begin{aligned} \text{apredikat3} &= \mu_{\text{Positif}}(7) \\ &= \min(\mu_{\text{Positif}}(7)) \\ &= \min(0.3; 0.8) \\ \mu_1 &= 0.3 \\ Z_1 &= -659 \end{aligned}$$

### 2.8.4 Defuzzyfikasi

At this stage, calculations will be carried out using the average formula (weight average) so that the defuzzification value is obtained as Eq. 1.

$$Z = \frac{\sum_i^n a_{\text{Predikat } i} \times z_i}{\sum_i^n a_{\text{Predikat}}} \quad (1)$$

$$Z = \frac{(0.3 \times 795) + (0.5 \times 250) + (0.3 \times (-659))}{(0.3 + 0.5 + 0.3)}$$

$$Z = 510$$

## 3 Results and Discussion

### 3.1 Prototype Testing

Testing the temperature control system with a feedback control system where the control system will compare the size of the process variable with the set value and then fix it to get rid of the error that occurred so that the effect of interference and load can be minimized. For testing done with different set values.

The first test was carried out at a set value of 33.5°C and an initial temperature of 29°C. Position the control is set to auto and calculated for every 0.5°C increase in temperature to temperature achieve the desired set value. So, the results of the graph in Fig. 8 are obtained.

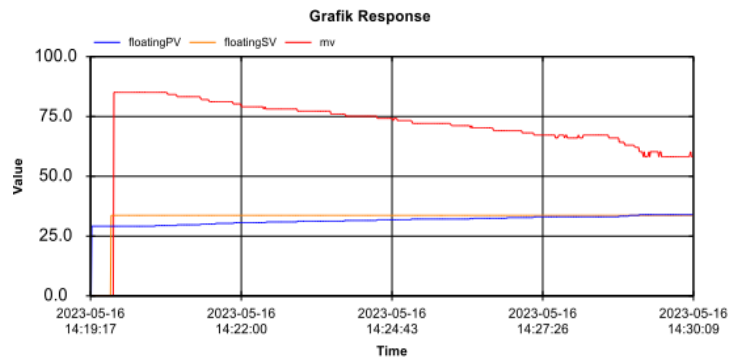


Fig. 8. Graph of SV change from 29°C to 33.5°C.

Based on Fig. 8, the response graph shows the results that the system responds from the first order and takes 630 seconds to reach the state stable. The system experienced a response delay of 315 seconds or about 5.2 minutes, temperature changes in the plant are quite slow because, in this process, fluid is not in a silent condition, and the MV value in the process is 85% to 62% when it reaches the set value. In the picture, it can be seen after it stabilizes at the set value. There should be no offset in the system. The characteristics of the resulting response as shown in Table 3.

Table 3. SV change response characteristics from 29°C to 33.5°C

Response characteristics	Parameters
Time constant	398.16 seconds
Rise time	630 seconds
Delay time	315 seconds
Overshoot	0
Error steady state	0

The second test was carried out at a set value of 37°C and an initial temperature of 33.5°C. Position the control is set to auto and calculated for every 0.5°C increase in temperature to temperature achieve the desired set value. So, the results are obtained in Table 4.

Table 4. SV change response characteristics from 33.5°C to 37°C

Response characteristics	Parameters
Time constant	881.008 seconds
Rise time	1394 seconds
Delay time	697 seconds
Overshoot	0
Error steady state	0

Based on Fig.9, the response graph shows the results that the system response forms a single order and takes 1394 seconds or about 23.3 minutes to achieve stability. The system experienced a response delay of 697 seconds or about 11.6 minutes, the change in temperature at the plant is quite slow due to the heating process on a fluid that is already hot and not in a state of rest is very difficult, and the MV value of the process is 81% to 62% of the time reach the set value. In the picture, it can be seen after it stabilizes at the set value. There should be no offset in the system. And produce a characteristic response that as shown in Table 4.

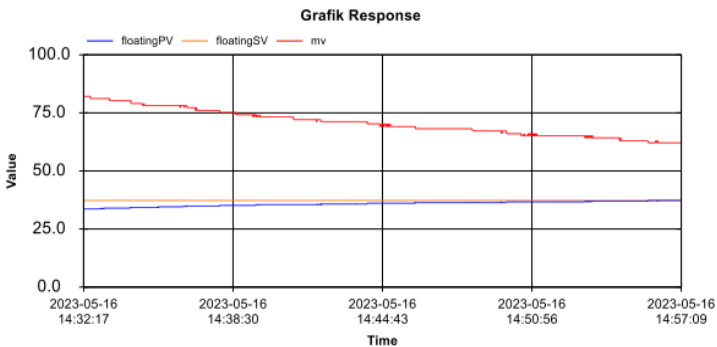


Fig. 9. Graph of SV change from 33.5°C to 37°C.

After testing by changing the set value, then it is done disturbance testing. Fig.10 is a disturbance in the form of 4 ice water liter with a temperature of 13°C causing variable process changes, the purpose of giving disturbance is to test the response characteristics to maintain its cell value temperature.



Fig. 10. Added disturbance.

Giving disturbance when SV 37°C is done to see how the controller faces the disturbance that occurs. Fig.11 shows a response graph when there is a sudden drop in temperature. When giving disturbance temperature, which was initially 37°C and MV 62% decreased to 34.6°C and the MV rose to 77%, and the time it takes for the PV to turn back on the cooled SV is about 36 minutes. The process of heating the fluid takes a long time. This is because the volume of fluid in the heater tank increases.

### 3.2 Data Analysis

Data analysis was carried out based on the results of the prototype experiment, the analysis, namely the observation of the system response in tests 1 and 2 which have been done.

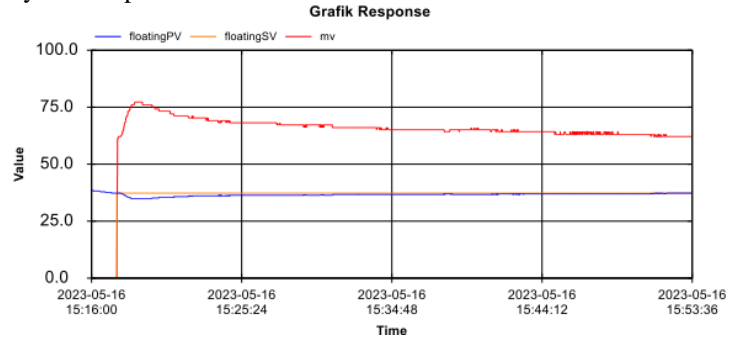


Fig. 11. Providingdisturbance when SV 37°C.

From the results of Fig. 12 and Fig. 13 testing 1 and 2, it can be seen that when the first test at a temperature of 29°C to 33.5°C takes 10.5 minutes to reach a stable state. Meanwhile, in the second test temperature from 33.5°C to 37°C takes about 23.3 minutes to reach a steady state. From these findings, it can be concluded that the heating of a fluid that has been hot and processes that are not in a state of rest will extend the process of heating the fluid. This may be caused by several factors, such as the capacity of the electric heater less capacity, which results in slow heating of the fluid.

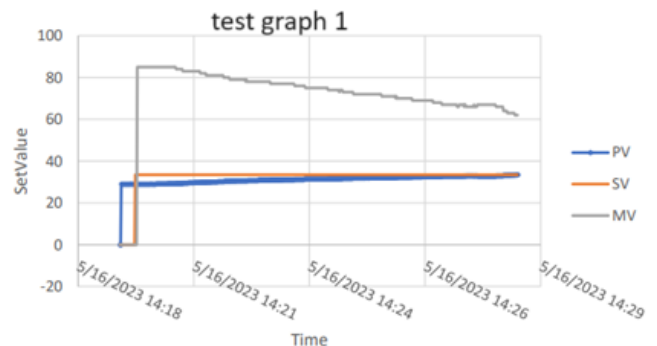


Fig. 12. First test graph.

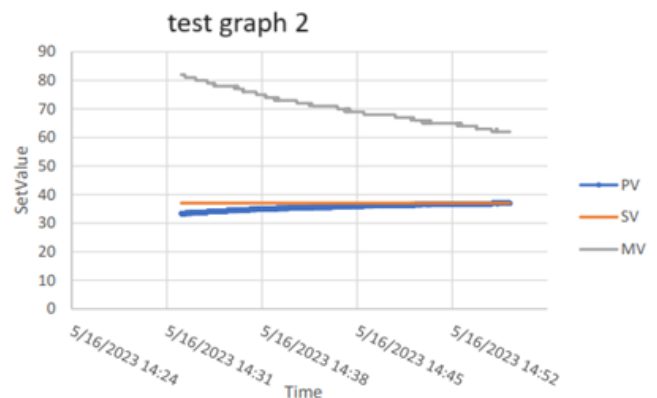


Fig. 13. Second testing graph.

Disturbance test by giving 4 liters of ice water with temperature 13°C, thus causing a change in the process variable; the purpose of giving disturbance is to test the response characteristics to maintain the cell value its temperature. From Graph 11 it is known that the controller can maintain Process Variable (PV) corresponding to setvalue nicely. The controller seeks to increase Manipulative Variable (MV) so that the PV temperature value can rise to reach the return set value. This effort was carried out by the controller because there was a decrease in the PV value from 37°C to 34.6°C at the 104<sup>th</sup> second as a result of giving disturbance directly to the inside heating tank. It takes 2160 seconds for PV to return to the set value state, its steady

state. The process of heating the fluid takes a long time because the volume of fluid in the heating tank increases. However, when the system returns at a set value of 37%, there is no oscillation or offset in the PV process (Fig. 14).

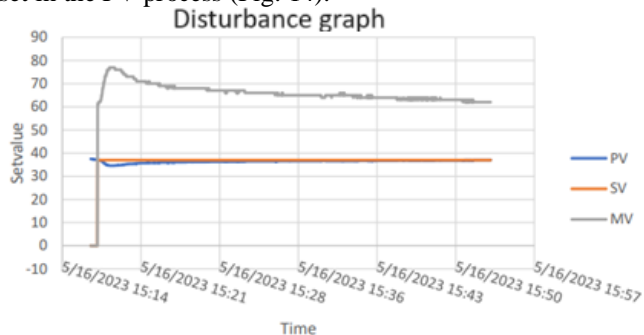


Fig. 14. Systemresponse graph with disturbance.

#### 4 Conclusion

The control system uses PLC Nano V5.2 as a controller that has a good ability to adapt to various conditions, environments or disturbances on the system and with the fuzzy method controls allow for flexible and capable temperature control to adapt to the changes that occur. From the results of tests 1 and 2, it can be concluded that the time required to reach a stable state at higher temperatures (33.5°C to 37°C) is longer than at lower temperatures (29°C to 33.5°C). These findings indicate that the heating of the fluid which has been hot and the process not in an idle state extends the warm-up time.

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