Design of a water heating system for automatic coffee maker using OMRON CP1E-NA20DR-A PLC and PID control

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Abstract. Various human activities require alternatives to replace activities such as making coffee drinks by providing automatic coffee drink makers. Automatic coffee makers require an accurate water heating system, while the water used to brew coffee drinks is not less than 80ºC and not more than 85ºC. This research designs a water heating system using an LM35DZ sensor as a temperature reader, an Omron-NA20DR-A PLC as a processor, and a heating tube used to heat water. PID algorithm is used to control the water temperature. The results of this study show that controlling water temperature using the PID algorithm with the Omron CP1E-NA20DR-A PLC can work well. The results of controlling the water temperature at a set point of 82ºC the system works with the parameter values Proportional Band = 20%, Integral Time = 50 seconds, and Derivative Time = 0.2 seconds resulting in a system response with a rise time value = 267 seconds, overshoot = 2.19 ºC, and peak time = 360 seconds.

1 Introduction

The development of the times goes hand in hand with human life which is getting very fast, it makes one human and another human compete and catch up in their respective countries [1]. Of course, this has an impact on the lives of each human being, especially on their life patterns, without exception in serving fast food and drinks [2]. The increasing human busyness makes humans want all their activities and activities to be faster, more effective, and efficient [3].

Human needs, namely food and drink, are also influential because these are basic human needs. Drinks such as coffee, tea, and milk are also human needs. In an automated and increasingly advanced world, many tools have been created to help and facilitate human work [4]. Of these types of drinks certainly require time in the manufacturing process [1]. Coffee is one of the agricultural crops that has many benefits, especially in the field of culinary, lifestyle and other needs [5]. At the beginning of its development coffee was only limited to being produced and consumed in Middle Eastern countries such as Saudi Arabia, but now it extends throughout the world and is widely consumed in Europe and America. The rapid development of coffee has made this drink part of the habits and culture of rural and urban communities [6]. The majority of the Indonesian population likes coffee drinks as an

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energizing dish and a dish during leisure time [7]. Indonesia is the 4th largest coffee producer and exporter in the world [8].

Almost all groups of people are very interested in coffee drinks, but in the process of making it requires a very long time [9]. In brewing coffee drinks, temperature also influences the taste of coffee drinks, so that the taste in making coffee drinks can match equally [10]. Temperature itself is a physical quantity that flows from a higher temperature to a lower temperature [7]. While the minimum technical requirements for water temperature for brewing coffee drinks, which is not less than 80 ° C and not more than 85°C [11]. Stability in a certain parameter will definitely affect the results of the product produced [12].

In serving coffee drinks there is a way to make it easier to make it, namely by designing a control system or control by utilizing an automatic way using a microcontroller [13]. Automation is a trend in society to facilitate human activities [14]. Microcontroller control can control on and off conditions properly [15]. The needs of technology are increasingly advanced, demanding the development of a reliable control system. A good control system is needed to increase efficiency in the production process, for example, temperature control automation [16]. Automatic control can be done by various types of controllers, one of which is PLC (Programmable Logic Controller). In the industrial world PLC can operate accurately and quickly and can increase productivity in terms of quality and quantity [17]. PLC can implement control of various types of processes through digital and analog input and output modules [18]. PLC is used as a solution to control a water heater object. Controlling the water heater uses a temperature sensor. The use of the sensor is to detect the temperature used in the operation of controlling the water heater [17]. To get precise water temperature control results, a Proportional Integral Derivative (PID) control system is needed [19]. The way this system works is by determining the desired temperature set point, then the temperature is kept stable with a small error value [20].

From some of these explanations, the author underlies the author to design a water heating system in an automatic coffee maker using an Omron CP1E PLC. The design of this heating system uses PIDAT instructions to control the water temperature [21]. This research is designed using a waterproof LM35DZ sensor to measure water temperature, LM35DZ Module to increase the LM35DZ sensor voltage as a fulfillment of the value at the PLC analog input, PLC OMRON CP1E-NA20DR-A as a system control device, SSR (Solid State Relay) as a water heater switch, and a water heater tube used to heat the water temperature. Solid state relay (SSR) is an electronic switch that has no moving parts, for example opto-coupler SSR, transformer-coupled SSR, and hybrid SSR. This solid state relay is equipped with an insulator in the form of an MOC component that functions to separate the input and switch parts [22]. The working principle of this tool is that the LM35DZ sensor reads the water temperature then the temperature data is sent to the PLC for processing then the PLC sends a control signal to control the water heater.

2 Material and Methods

2.1 System Design

Figures From the system design there are two parts, namely hardware design and software design. The hardware design is arranged with block diagrams and wiring diagrams, while the software design is arranged in the form of flow charts.

2.2 Hardware Design

The hardware design is made in a block diagram. The block diagram can be seen in Figure 1.

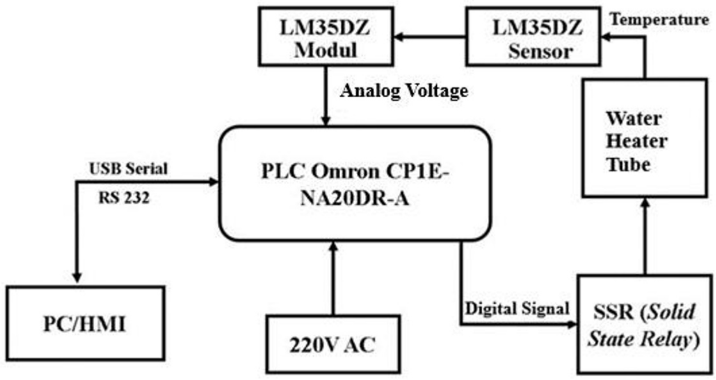

Fig. 1. System Block Diagram

This temperature control system design uses an Omron CP1E-NA20DR-A PLC which functions as a system controller and processes temperature reading data from the LM35DZ Sensor Module. While the actuator used is a water heater tube. The PLC provides an output signal in the form of a digital signal to activate the SSR (Solid State Relay) and activate the heating element on the water heater tube. PC / computer is used to create a program using CX-Programmer software and HMI on CX-Designer software then communicated with PLC using USB cable and RS 232 cable.

In order for temperature control to produce stable accuracy, a PID controller system is designed. The design of the PID controller system aims to regulate the water heating element to reach the set point value according to the instructions that have been entered. So that the water heater will turn off when the water temperature has reached the set point. The block diagram of the temperature controller can be seen in Figure 2.

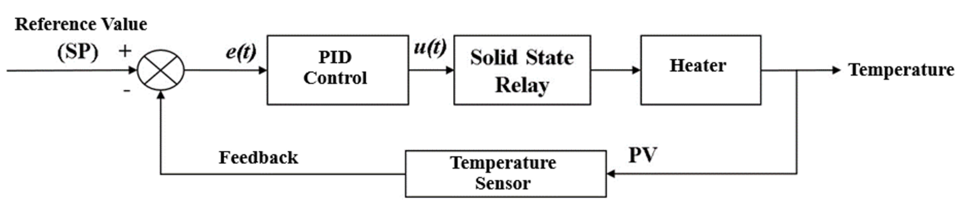

Fig. 2. Temperature Controller Block Diagram

2.3 System Wiring Diagram

The system wiring diagram is used to make it easier when designing hardware. The system wiring diagram can be seen in Figure 3.

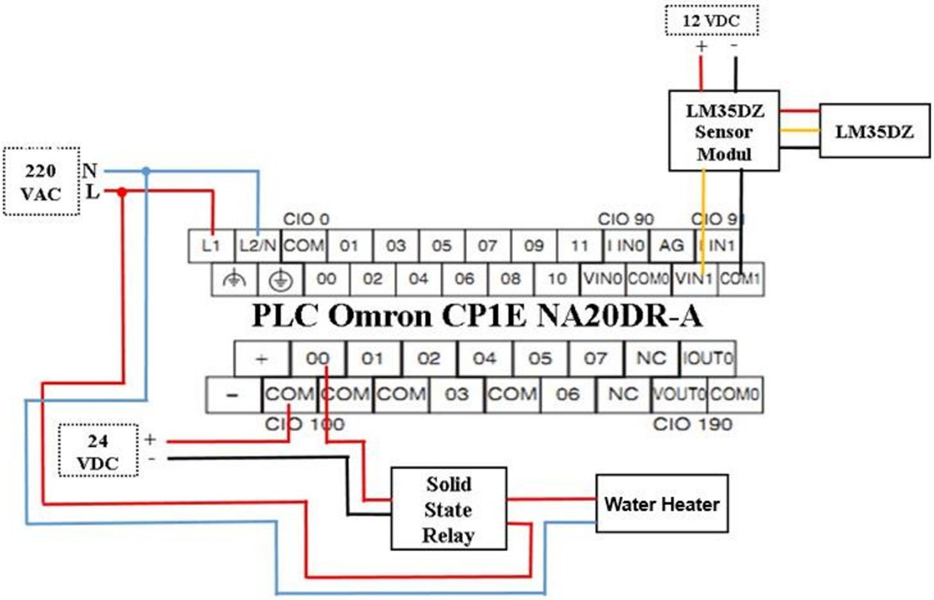

Fig. 3. System Wiring Diagram

The PLC controller gets a voltage source of 220V AC. In addition, 12V DC and 24V DC voltage sources are also used to be the voltage source for the LM35DZ Sensor Module and SSR (Solid State Relay). The LM35DZ Sensor Module provides output in the form of a voltage with a range of 0-10V DC, which is connected to CIO 91. SSR (Solid State Relay) gets input from PLC output 100.00 to activate the water heater. The system input and output table can be seen in Table 1.

Table 1. System Inputs and Outputs

No	Component	Input	Output
1	LM35DZ sensor module	Temperature 0-100°C	0-10V DC
2	PLC Omron CP1E-NA20DR-A	Power Supply 220 V AC CIO 91: Analog 0-10 V	CIO 00: 24 V DC
3	SSR (Solid State Relay)	Voltage 24 V DC	220 V AC
4	Water Heating Tube	Voltage 220V AC	Temperature 0-100°C

The LM35DZ sensor requires an LM35DZ module so that the LM35DZ sensor output value can be accepted by the Omron CP1E-NA20DR-A analog PLC. The LM35DZ module has the function of amplifying the LM235DZ sensor output voltage signal, which initially has an output value of 10mV/°C to ten times or to 100mV/C. The LM35DZ module circuit can be seen in Figure 4.

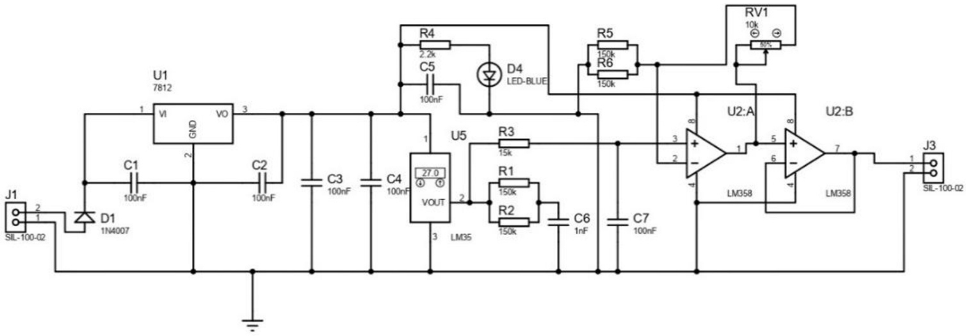

Fig. 4. Schematic of LM35DZ Module

2.4 Software Design

There are 2 stages of software design, namely the temperature control system program flow diagram and the design of the Human Machine Interface (HMI). The program flow begins with reading the temperature value by the LM35DZ sensor, then scaling is carried out so that the value displayed can be a value of °C on the HMI. The result of scaling the value is used as the PV (Present Value) value. The next step is to enter the Set Point value. In this study, the set point value used is 82°C. Then select the mode to be used, namely manual or autotuning mode. Manual mode is done by entering the Set Point value, PID parameters, and also sampling time. Autotuning mode is done by entering the Set Point value, sampling time, and PID parameters arbitrarily, this is done to help the autotuning bit activation process. The values that have been entered will be processed to produce MV (Manipulated Variable) values as system output commands to activate the water heater.

2.5 HMI Design (Human Machine Interface)

HMI (Human Machine Interface) design is done using CX-Designer software. HMI is used to observe the Set Point input value, PID parameters, sampling time, and the measured temperature of the LM35DZ Module. The HMI display can be seen in Figure 5.

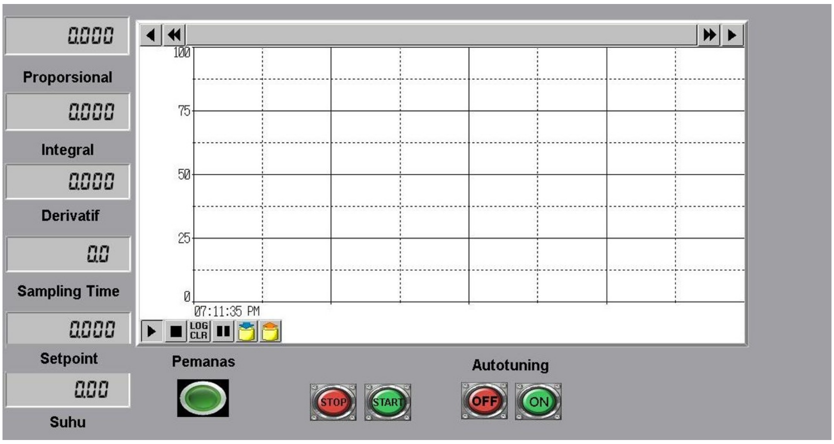

Fig. 5. HMI Display of Temperature Control System

In general, PID constants are in the form of Proportional (Kp), Integral (Ki), and Derivative (Kd) constants, but the PIDAT instructions used in PLCs use Proportional Band (PB), Integral Time (Tik), and Derivatve Time (Tdk) parameters.
The Proportional Band (PB) equation is:

$$PB = 100/Kp \tag{1}$$

The Integral Time (Tik) equation is :

$$\text{Ki} = \frac{Kp}{Tik} \tag{2}$$

The Time Derivative Equation (Tdk) is:

$$Kd = Kp \times Tdk \tag{3}$$

With:
PB = Proportional Band (%)
Kp = Proportional Constant
Ki = Integral Constant
Tik = Integral Time (s)
Kd = Derivative Constant
Tdk = Derivative Time (s)

3 Results and Discussion

3.1 LM35DZ Module Testing

The function of the LM35DZ module is to amplify the output signal from the LM35DZ sensor to 10 times the linearity of 10mV/°C to 100mV/°C. Testing of the LM35DZ module is carried out to observe the increase in temperature and output voltage from the module. This test is carried out by heating water in a heating tube and measuring the temperature with a digital thermometer simultaneously and observing the output voltage of the LM35DZ module. The way of testing is by observing every increase in voltage and temperature and measuring the temperature from 29.5 ° C to 81.1 ° C. The results of the tests carried out; the results obtained can be seen in Table 2. The temperature rise graph can be seen in Figure 6.

Fig. 6. LM35DZ module testing

Table 2. Temperature and Voltage Data of LM35DZ Module

No	Water Temperature (ºC)	Module Output Voltage (V)	Difference
1	29.5	2.99	0.4
2	34.5	3.49	0.4
3	40.8	4.16	0.8
4	44.9	4.52	0.3
5	50.6	5.16	1
6	55.2	5.59	0.7
7	64.4	6.56	1.2
8	70.6	7.12	0.6
9	75.7	7.65	0.8
10	81.1	8.21	1
∑Total			7.2
Average			0.72

3.2 Water Heater Tube Testing

Testing the water heating tube is done to determine the speed of the heating element in the heating tube in raising and lowering the water temperature. This test includes testing the speed of the heating element in raising and lowering the water temperature. The test was carried out by heating water in a heating tube with a volume of 600 ml and observing the increase in temperature with sampling per 30 seconds for 9.5 minutes. Data from the heating speed test can be seen in Table 3. The temperature drop is also measured every 30 seconds. The results of the temperature drop measurement can be seen in Table 4. From the data that has been obtained, it can be seen that the temperature drop lasts longer than the temperature increase. This is because the water heating tube is not equipped with a cooler. The comparison between temperature increases and temperature decrease is presented in the form of a graph and can be seen in Figure 7.

Table 3. Water heater speed data

No	Time (s)	Temperature (ºC)
1	0	29.3
2	30	30.9
3	60	34.1
4	90	37.3
5	120	40.1
6	150	42.8
7	180	45.3
8	210	47.8
9	240	50.5
10	270	52.9
11	300	55.7
12	330	58.2
13	360	60.8
14	390	63.3
15	420	65.8
16	450	68.3
17	480	70.9
18	510	73.3
19	540	75.5
20	570	77.9

Table 4. Water temperature drop data

No	Time (s)	Temperature (ºC)
1	0	85
2	30	84.6
3	60	84.1
4	90	83.6
5	120	83.1
6	150	82.8
7	180	82.3
8	210	81.9
9	240	81.5
10	270	81.1
11	300	80.6
12	330	80.3
13	360	79.8
14	390	79.3
15	420	78.9
16	450	78.6
17	480	78.3
18	510	77.9
19	540	77.5
20	570	77.1

3.3 PI Controller Testing

Testing the temperature control system using the Proportional Integral (PI) controller is done by trial and error method. This experiment includes varying parameters for 3 trials by heating 600 ml of water in a water heater tube that is heated constantly.

a) Parameter Testing PB=1%, Tik=1s, Tdk=0s

This test was carried out by entering the parameter value P = 1%, I = 1s, D = 0s, sampling time of 0.5s, and set point of 82ºC. The graph results can be seen in Figure 7.

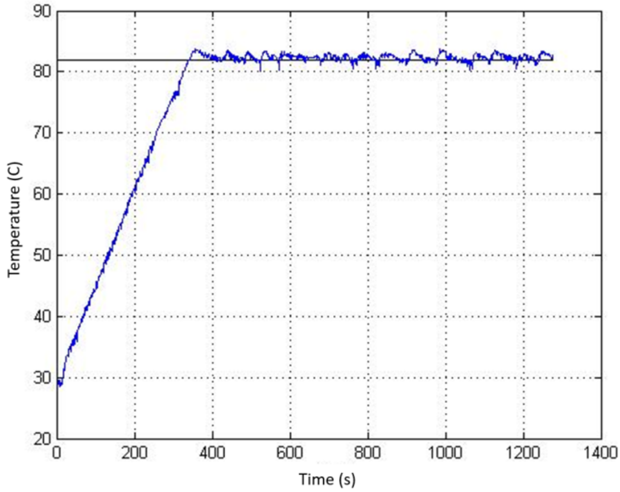

Fig. 7. Testing results on parameters PB = 1%, Tik = 1s, Tdk = 0s

Testing temperature control with PID tuning manually produces a system response, with a rise time = 271 seconds, overshoot = 2.07ºC, and peak time = 356 seconds.

b) Parameter Testing PB=1%, Tik=100s, Tdk=0s

This test was carried out by entering the parameter value of P = 1%, I = 100s, D = 0s, sampling time of 0.5s, and a set point of 82ºC. The graph results can be seen in Figure 8.

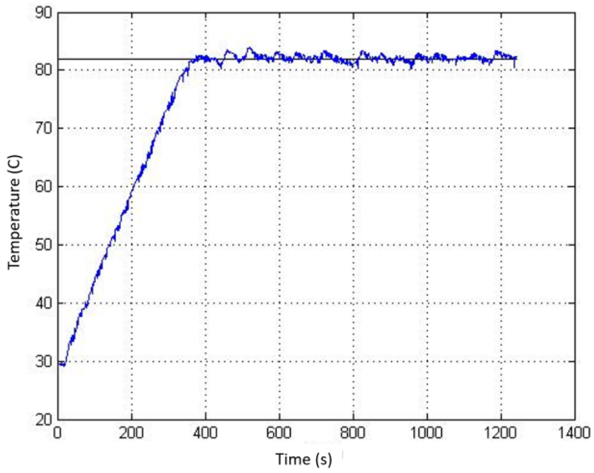

Fig. 8. Test results on parameters PB = 1%, Tik = 100s, Tdk = 0s

Testing temperature control with PID tuning manually produces a system response, with a rise time = 274 seconds, overshoot = 2.31 ºC, and peak time = 517 seconds.

c) Parameter Testing PB = 2%, Tik = 50s, Tdk = 0s

This test was carried out by entering the parameter value P = 2%, I = 50s, D = 0s, sampling time of 0.5s, and set point of 82ºC. The graph results can be seen in Figure 9.

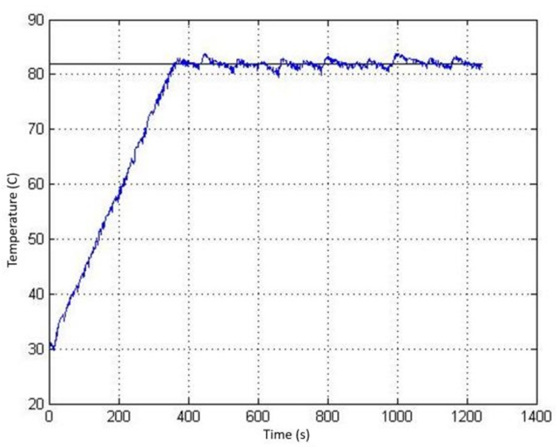

Fig. 9. Test results on parameters PB = 2%, Tik = 50s, Tdk = 0s

Testing temperature control with PID tuning manually produces system responses with a rise time value = 281 seconds, overshoot = 2.19°C, and peak time = 997 seconds.

3.4 PID Controller Testing

Testing the temperature control system using a Proportional Integral Derivative (PID) controller is done by trial and error method. This experiment includes varying parameters for 3 trials by heating 600 ml of water in a water heater tube that is heated constantly.

a) Parameter Testing PB = 65%, Tik = 0.2s, Tdk = 0.1s
This test was carried out by entering the parameter value P = 65%, I = 0.2s, D = 0.1s, sampling time of 0.5s, and set point of 82ºC. The graph results can be seen in Figure 10.

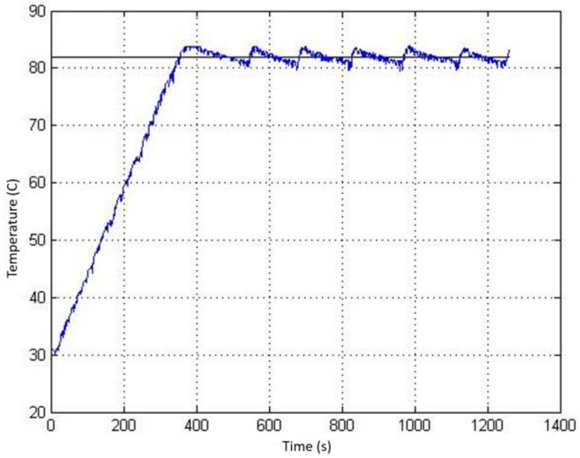

Fig. 10. Testing results on parameters PB = 65%, Tik = 0.2s, Tdk = 0.1s

Testing temperature control with PID tuning manually produces a system response, with a rise time value = 265 seconds, overshoot = 2.31°C, and peak time = 987 seconds.

b) Testing results on parameters PB = 65%, Tik = 0.2s, Tdk = 0.1s
This test was carried out by entering the parameter value P = 40%, I = 0.2s, D = 0.1s, sampling time of 0.5s, and set point of 82ºC. The graph results can be seen in Figure 11.

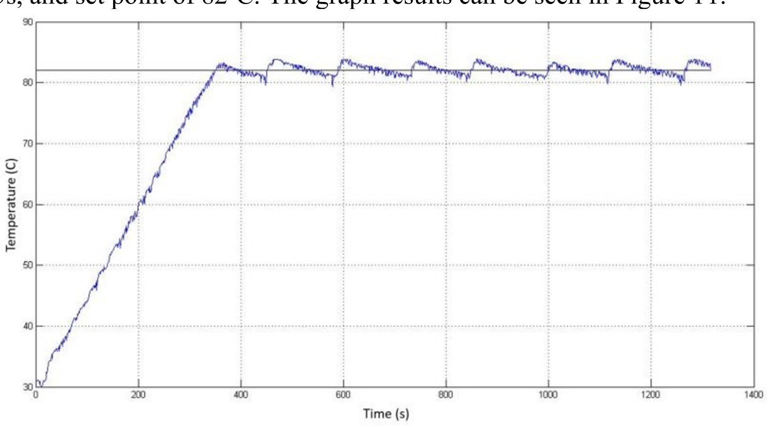

Fig. 11. Test results on parameters PB = 40%, Tik = 0.2s, Tdk = 0.1s

Testing temperature control with PID tuning manually produces a system response, with a rise time value = 273 seconds, overshoot = 2.31ºC, and peak time = 861 seconds.

c) Parameter Testing PB = 20%, Tik = 50s, Tdk = 0.2s

This test was carried out by entering the parameter value P = 20%, I = 50s, D = 0.2s, sampling time of 0.5s, and set point of 82ºC. The graph results can be seen in Figure 12.

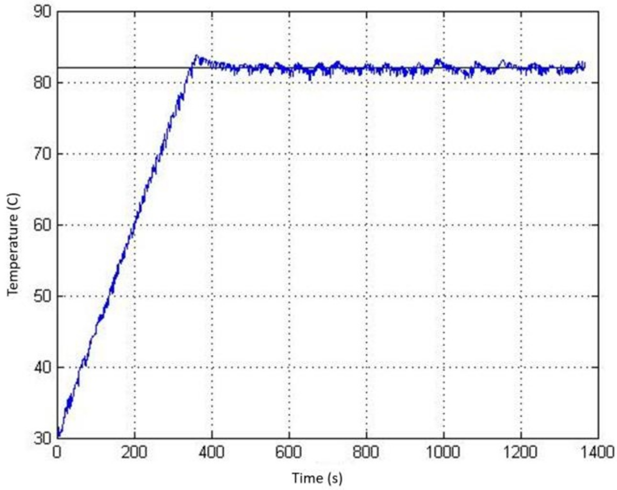

Fig. 12. Test results on parameters PB = 20%, Tik = 50s, Tdk = 0.2s

Testing temperature control with PID tuning manually produces system responses, with a rise time value = 267 seconds, overshoot = 2.19ºC, and peak time = 360 seconds.

4 Conclusion

This study successfully implemented a temperature control system using an Omron CP1E-NA20DR-A PLC as a system control device. The results of the temperature control system using a PI controller show the most stable system response to the parameters PB = 1%; Tik = 1s; Tdk = 0s with a rise time = 271s; overshoot = 2.07 ° C; and peak time = 356 s.The results of the temperature control system using the PID controller show the most stable system response at PB = 20%; Tik = 50s; Tdk = 0.2s with a rise time value = 267s; overshoot = 2.19°C; and peak time = 360s.

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