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PERFORMANCE EVALUATION FUZZY LOGIC CONTROL ON LOW-COST MEDICAL EQUIPMENT STERILIZER

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Abstract, The equipment is not sterile when the health equipment is used repeatedly. Thus, it is at risk of infection. Data published by WHO reveals that one out of every ten hospital patients gets an infection. In developed countries, the number of infected hospital patients reaches 30%, while in developing countries it is at least 2-3 higher. One way to reduce the occurrence of infection is to sterilize medical equipment through a dry heat sterilization process at 1700 C for 60 minutes. The high price of sterilizers means that many health centers and clinics do not have this equipment. The aim of this study was to design a low-cost dry heat type health equipment sterilizer using fuzzy logic as a controller and evaluate the performance of the controller. Regarding to the research result, it indicated that the controller performance evaluation was very good with the highest overshoot value of 1.1%, the steady state error value was 1.1%, and the fastest rise time was 240 seconds.

Keywords: fuzzy logic, temperature control, Arduino Uno, sterilization.

I. INTRODUCTION

Health equipment is very essential for health workers when examining, treating or caring for patients (Taufik et al., 2019). Several health equipments can be used for single use, such as syringes, urine collection devices, masks, feeding aid tubes and so on. However, there are also medical devices that can be used repeatedly, such as scissors, knives and other equipment made of iron or glass. The repeated use of medical devices can of course cause the equipment to be contaminated with microorganisms (bacteria, viruses and parasites) that can cause infection in patients or health workers (Rutala & Weber, 2013, 2019).

In accordance with data from the Ministry of Health, the number of infections that occur in hospitals continues to increase, it reaches 9% or more than 1.4 million inpatients worldwide (Alvarado, 2000). The results of a point prevalence survey from 11 hospitals in DKI Jakarta conducted by Perdalin Jaya and Dr. Sulianti Saroso Jakarta obtained a nosocomial infection rate or infection that occurred in ILO hospitals (surgical wound infections) of 18.9%. UTI (Urinary Tract Infection) 15.1%, IADP (Primary Stream Infection) 26.4%, Pneumonia 24.5%, other respiratory infections 15.1%, and other infections 32.1% (Kemenkes, 2018).

The latest data published by WHO (World Health Organization) in 2016, one out of every ten hospital patients has an infection (WHO, 2016). In developed countries, the number of infected hospital patients reaches 30%, while in developing countries it is at least 2-3 higher. One of the causes of death for babies born in hospitals is infection, with the number of infant deaths due to infection reaching 56% (WHO, 2016). Infection rate due to medical devices Intra-aortic balloon pump is 0.08-0.13%, Left ventricular assist device is 16-36%, Cardiac valve is 7-15%, Cardiac implantable electronic device is 5-20%, Mesh for ventral hernia repair by 1-10%, Ventriculoperitoneal shunt by 0.25-1%, Peritoneal dialysis catheter by 20% (VanEpps & Younger, 2016).

To minimize the risk of nosocomial infections, the Minister of Health of the Republic of Indonesia issued a ministerial regulation on handling infections, in the Ministerial Decree it was explained that one way to reduce the rate of infection is to carry out a sterilization process on medical equipment that will be and has been used.

The sterilization process aims to remove all microorganisms (bacteria, viruses and parasites) including endospores using high pressure steam (autocaf), dry heat (oven), chemical sterilization or radiation (Kemenkes, 2017).

Not all primary clinics or hospitals have sterilizers because they are relatively expensive (Taiwo Mubarak et al., 2019) Therefore, this study intends to design a low-cost dry heat sterilizer using the Arduino Uno microcontroller with a Fuzzy logic controller and evaluate the performance of the controller. The fuzzy control system has more robust properties than the PID control system (Batayneh, 2015; Kaur, 2012; Rakhmawati et al., 2018), the fuzzy control system is easy to modify because it uses rules that describe operator strategies in scientific language, fuzzy control systems easy to understand, how to design it, and how to apply it (Mendel, 2014). Further, building a fuzzy control system is cheaper than building a control system based on a model (Precup & Hellendoorn, 2011). The sterilizer designed in this study is of the dry heat type because it can sterilize several types of materials that cannot be penetrated by steam such as dry powders and oil materials, does not have corrosive properties to metals, through a conduction mechanism can reach the entire surface of the tool which cannot be disassembled and assembled. The sterilizer follows the Minister of Health regulations regarding medical equipment sterilizers (Kemenkes, 2014).

II. METODOLOGI PENELITIAN

The sterilizer box in this study was designed in accordance with the provisions which required in the ministerial regulation regarding medical equipment sterilizers, namely a minimum capacity of 78 liters or 0.078 m^3 (Kemenkes, 2014). The size of the sterilizer box designed in this study was 0.10 m^3, which can be seen in Figure 2.1 below:

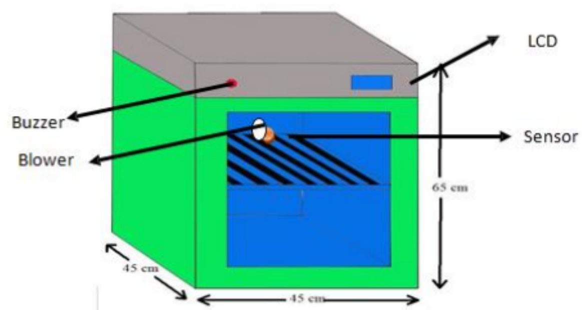


Figure 2.1. Sterilizer box design

The main part of the sterilizer box consisted of a blower heater which distributed heat to the sterilizer chamber or room, a buzzer was used as an alarm, and an LCD was used to display the process that was happening. Whereas, the block diagram of the system is shown in Figure 2.2 below:

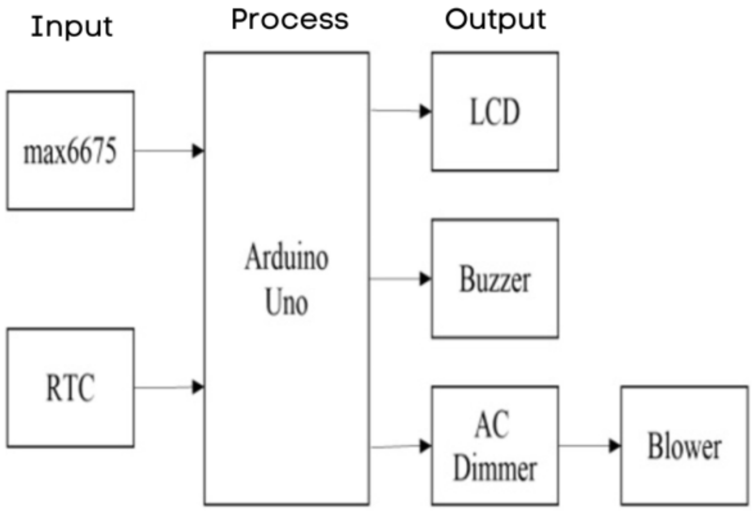


Figure 2.2 System Block Diagram

The block diagram of the system consisted of Arduino uno and it was used as a place to process data received from input and manages the overall system where fuzzy logic was embedded in it. Max6675 used was to provide temperature information in the sterilizer to arduino. The RTC (Real Time Clock) which works as a timer will provide information on how long the sterilization process will take or has been carried out. The AC Dimmer circuit functions as a voltage regulator driver on the Blower so that the heat obtained can be conditioned or regulated. The function of the blower is as a heat generator. The working principle is that the hot air produced by the blower will flow into the sterilizer. While the buzzer functions as an alarm. If the sterilization process is complete, Arduino will instruct the buzzer to sound. A. An LCD is also installed on the sterilizer to display information on temperature, date, day, time and process status whether it has been completed or is still in process.

The following circuit for the entire system with its pin configuration is shown in Figure 2.3.

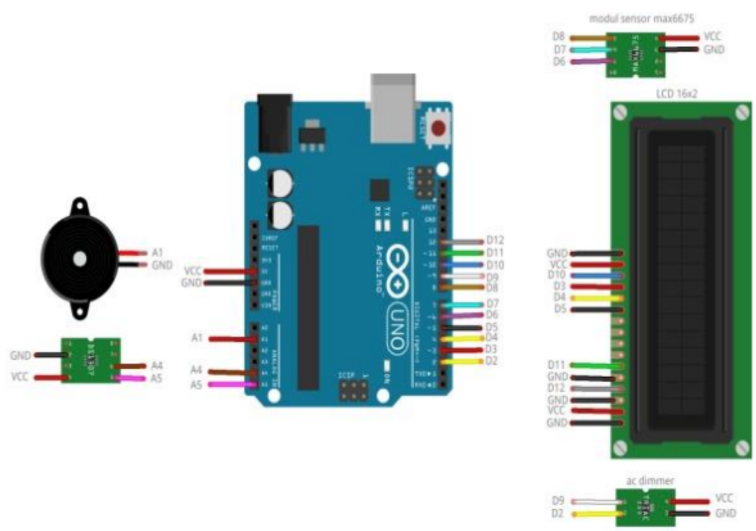


Figure 2.3. Circuit for the Entire System

The control method in this study used fuzzy logic, the design of fuzzy logic was divided into several parts, namely the fuzzification stage, the rules-base formation stage, inference, and the last stage was the defuzzification stage.

The fuzzification stage began with determining the membership function of the Fuzzy Logic Set of Error Variables at Temperature. The set point of the system in this study was 1700 C with a lower limit of 1600 C and an upper limit of 1800 C. Thus, the error ranges obtained were -10 and +10. These results were obtained by subtracting the lower limit from the set point and subtracting the upper limit from the set point. Moreover, membership function of the fuzzy logic set variable error at temperature can be seen in Figure 2.4

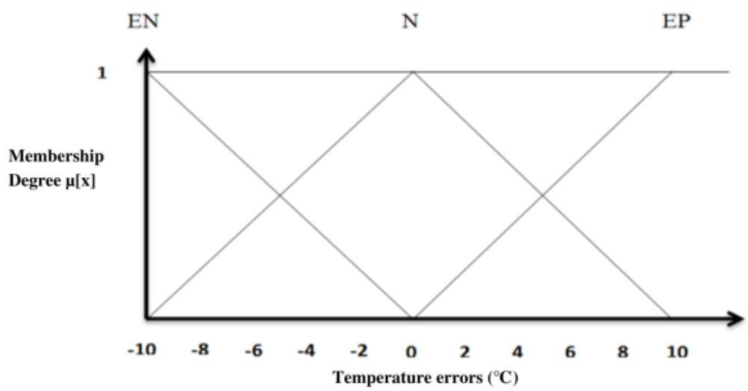


Figure 2.4. Fuzzy Set Membership Function on Temperature Error Variable

Dealing with Figure 2.4, it is known that the error variable has three sets, namely EN (Negative Error), N (Zero), and EP (Positive Error). The fuzzy set M has a domain [-10,0], N has a domain [-10,10], and P has a domain [0,10].

$$\mu_{EN} = \begin{cases} 1; & x \leq -10 \\ \frac{0-x}{0-(-10)} & -10 \leq x \leq 0 \\ 0; & x > 0 \end{cases}$$

$$\mu_{N} = \begin{cases} 0; & x \leq -10 \\ \frac{x-(-10)}{10-(-10)} & -10 \leq x \leq 10 \\ \frac{3-x}{10-(-10)} & 0 \leq x \leq 10 \\ 0; & x > 0 \end{cases}$$

$$\mu_{EN} = \begin{cases} 0; & x \leq 0 \\ \frac{x-0}{10-0} & 0 \leq x \leq 10 \\ 1; & x > 10 \end{cases}$$

Membership Function of Fuzzy Logic Set Delta Error Variable at Temperature to find out the value of the delta error variable, it is necessary to measure the temperature of the system you want to control first. After measuring the temperature of the system, to get the system error delta can be known by using the equation below:

$$Delta\ error = |\ error_n| - |\ error_{n-1}\ | \qquad (3.1)$$

Dealing with the observation, the value for the delta error is -14 to 10. Membership Function of Fuzzy Logic Set Variable Delta Error at Temperature is shown in Figure 2.5.

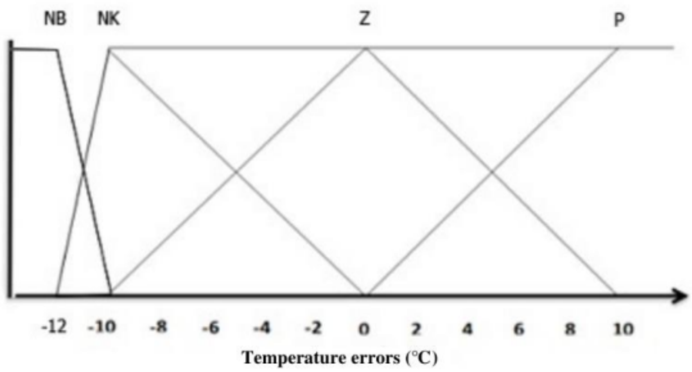


Figure 2.5. Membership Function of Fuzzy Logic Set Variable Delta Error

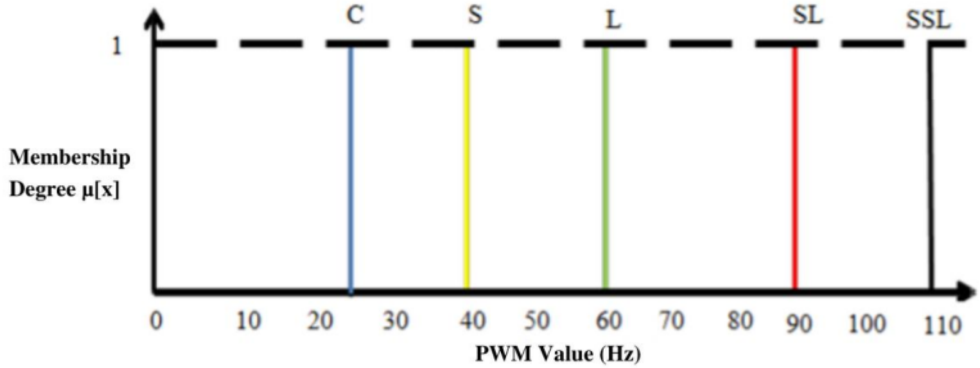
$$\mu_{NB} = \begin{cases} 1; & x \le -12 \\ \frac{-10-x}{-10-(-12)} & -12 \le x \le 10 \\ 0; & x > 10 \end{cases}$$

$$\mu_{Nk} = \begin{cases} 0; & x \le -12 \\ \frac{x-(-12)}{-10-(-12)} & -14 \le x \le 10 \\ \frac{0-x}{0-(-10)} & -10 \le x \le 0 \\ 0; & x \le -10 \end{cases}$$

$$\mu_{z} = \begin{cases} 0; & x \le -10 \\ \frac{x-(-10)}{0-(-10)} & -10 \le x \le 0 \\ \frac{10-x}{10-0} & 0 \le x \le 10 \\ 0; & x \le 0 \end{cases}$$

$$\mu_{EN} = \begin{cases} 0; & x \le 0 \\ \frac{x-0}{10-0} & 0 \le x \le 10 \\ 1; & x > 10 \end{cases}$$

The next stage is the Membership Function of the Output Variable Fuzzy Logic Set. The output variable in the temperature control is PWM which functions to control the Ac Dimmer. Fuzzy sets on output variables The output variables are divided into 4 fuzzy sets, namely SL (Very Slow), L (Slow), S (Medium), C (Fast). SL has 100 domains, L has 60 domains, S has 40 domains, C has 30 domains. As shown in figure 2.6.



Gambar 2.6 Fungsi Keanggotaan Himpunan Logika *Fuzzy* Variabel *Output*

The next stage is Formation of Rules-base and Inference. The number of combinations between Error and Delta Error is 12 combinations. Hence, there are 12 rules that can be used in this study. The 12 rules are:

[R1] IF nilai error EN (Error Negatif) And nilai Delta error NB (Negatif Besar) THEN C (Cepat).
[R2] IF nilai error EN (Error Negatif) And nilai Delta error NK (Negatif Kecil) THEN C (Cepat).
[R3] IF nilai error EN (Error Negatif) And nilai Delta error Z (Zero) THEN C (Cepat).
[R4] IF nilai error EN (Error Negatif) And nilai Delta error P (Positif) THEN S (Sedang).
[R5] IF nilai error N (Netral) And nilai Delta error NB (Negatif Besar) THEN C (Cepat).
[R6] IF nilai error N (Netral) And nilai Delta error NK (Negatif Kecil) THEN S (Sedang).
[R7] IF nilai error N (Netral) And nilai Delta error Z (Zero) THEN L (Lambat).
[R8] IF nilai error N (Netral) And nilai Delta error P (Positif) THEN SSL (Sangat-sangat Lambat).
[R9] IF nilai error EP (Error Positif) And nilai Delta error NB (Negatif Besar) THEN SL (Sangat Lambat)
[R10] IF nilai error EP (Error Positif) And nilai Delta error NK (Negatif Kecil) THEN SL (Sangat Lambat)
[R11] IF nilai error EP (Error Positif) And nilai Delta error Z (Zero) THEN SSL (Sangat-sangat Lambat)
[R12] IF nilai error EP (Error Positif) And nilai Delta error P (Positif) THEN SSL (Sangat-sangat Lambat).

Whereas, the fuzzy logic rules are shown in table 2.1

Tabl2 2.1 Fuzzy Logic Rules

Error* / *Derror	**EN**	**N**	**EP**
NB	C	C	SL
NK	C	S	SL
Z	C	L	SSL
P	S	SSL	SSL

Defuzzification stage, the defuzzification process carried out in this study was Fuzzy Sugeno logic using the Weighted average method. The Sugeno method does not require time for defuzzification because the end result W_0 is a crisp value.

III. ANALISA DAN HASIL

The design results of the dry heat sterilizer box are shown in Figure 3.1. This sterilizer box has a capacity of 0.10 m3 which is equipped with a microcontroller and sensor module Max6675 as a temperature sensor, RTC (Real Time Clock) which works as a timer will provide information on how long the sterilization process will be or has been carried out, a blower unit used to generates heat which is regulated through a series of AC Dimmers, and a Buzzer that functions as an alarm.

Figure 3.1 Design Results of the Sterilizer Box

Each part of the sterilizer system is then tested, the results are shown in table 3.1, the test results reveal that all components can work according to their respective functions. The biggest blower voltage is when it is first turned on and the temperature has not reached the desired set point, in this case 170 0C. The biggest error in temperature control is 20 C or 1.1%, because the maximum error in this study is 5.9%, so in testing the entire system it can be concluded that the temperature control has been successful. While the buzzer has a voltage of 0 V since it was first turned on, but in the 60th minute the buzzer voltage suddenly becomes 5 V, this happens because the sterilization process has been completed and the buzzer will activate and give a warning when the sterilization process has been completed. The overall test was carried out.

Tabel 3.1 Hasil Pengujian *Keseluruhan Sistem*

No	Waktu sterilisasi (Menit)	Tegangan input *Blower*	Modul sensor max6675	Tegangan Input AC *Dimmer*	Input PWM AC *Dimmer*	*Timer* (*Buzzer*)
1	1	200 V	35 °C	220 V	25Hz	0 V
2	10	120 V	170 °C	220 V	72 Hz	0 V
3	20	123 V	171 °C	220 V	70 Hz	0 V
4	30	127 V	172 °C	220 V	71 Hz	0 V
5	40	127 V	172 °C	220 V	69 Hz	0 V
6	50	127 V	172 °C	220 V	70 Hz	0 V
7	60	124 V	171 °C	220 V	70 Hz	5 V

After testing for each component of the system that has been developed, then testing the sterilizer as a whole is carried out. The first test is shown in Figure 3.2. It can indicated that the time needed by the system for the temperature of the sterilization process to reach the set point is 234 seconds. After reaching the set point, the temperature for the sterilization process is quite stable around that set point. In the first test the system did not experience overshoot while the steady state error value was 1.7%.

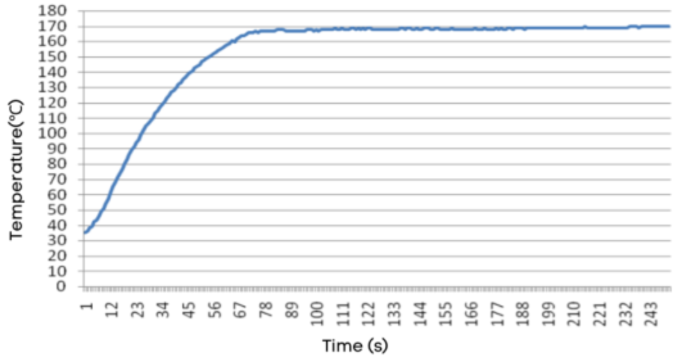


Figure 3.2. First Test Results for Stability of the Sterilizer Temperature

The second sterilizer temperature stability test is shown in Figure 3.3. It can be seen that the time needed for the system to reach the set point temperature is 80 seconds. This time is quite different from the first experiment which took 234 seconds. So the difference between the first and second try is 154 seconds. Even though this time was quite short, in this second experiment the system experienced an overshoot of 0.5% because after reaching the set point the temperature of the sterilization process continued to rise up to 1710 C. while the steady state error value in this second experiment was smaller than in the first experiment, namely 0.5%.

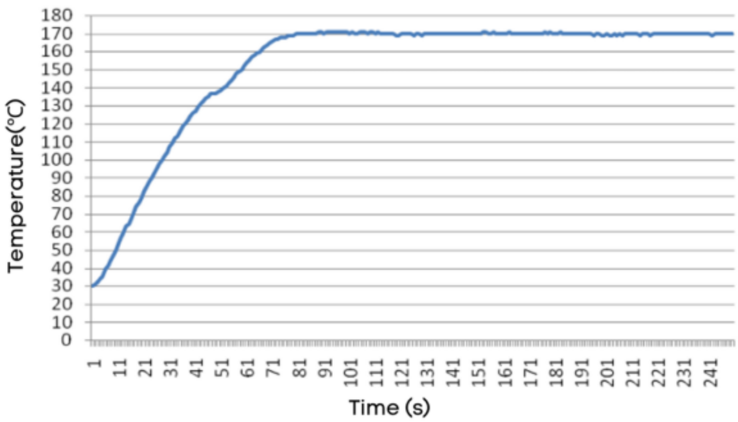
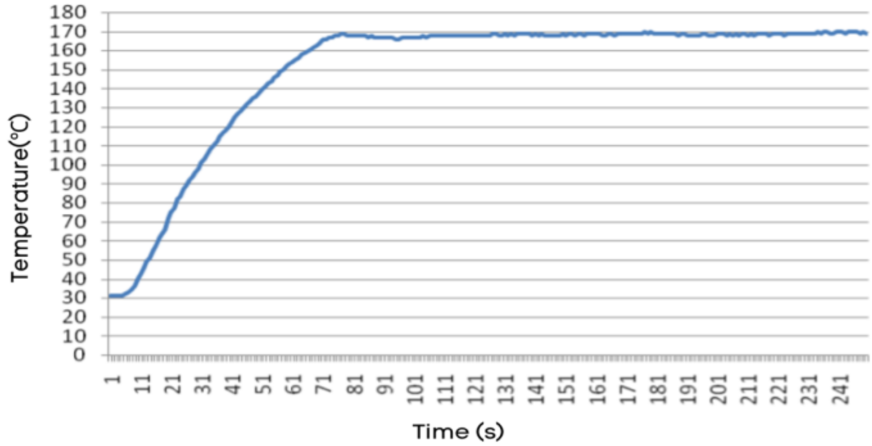


Figure 3.3. The results of the second test are the stability of the temperature of the sterilizer

In the third test, the results are as shown in Figure 3.4, the time needed for the system so that the temperature of the sterilization system reaches the set point is 230 seconds, the system also does not experience an overshoot or the system overshoot value is 0 (zero). Meanwhile, the steady state error value in this third experiment was 1.1%.



Gambar 3.4. Hasil Pengujian ketiga Kestabilan Suhu sterilisator

The three test results above show that the sterilization of medical equipment based on Arduino Uno using fuzzy logic control is designed to not experience problems in each component used because each of these components can function as it should and there are no errors either from the hardware side or from the software side, besides it can also be seen that the rise time value affects the overshoot value.

To ensure the system can work properly, testing with interference is also carried out, and the results are shown in Figure 3.5. As long as the sterilization process lasts for approximately one hour, distraction is given three times. The first disturbance causes the temperature of the sterilization process to drop below 1600 C, occurring at 460 seconds during the sterilization process, but in a few moments the system can adjust again so that the temperature of the sterilization process returns to the set point at 578 seconds. After reaching the set point for the second time, the system does not experienced an overshoot. The second disturbance was given at 1114 seconds and the temperature again reached the set point at 1200 seconds. Meanwhile, the third disturbance was given at 2536 seconds and the temperature again reached the set point at 2666 seconds.

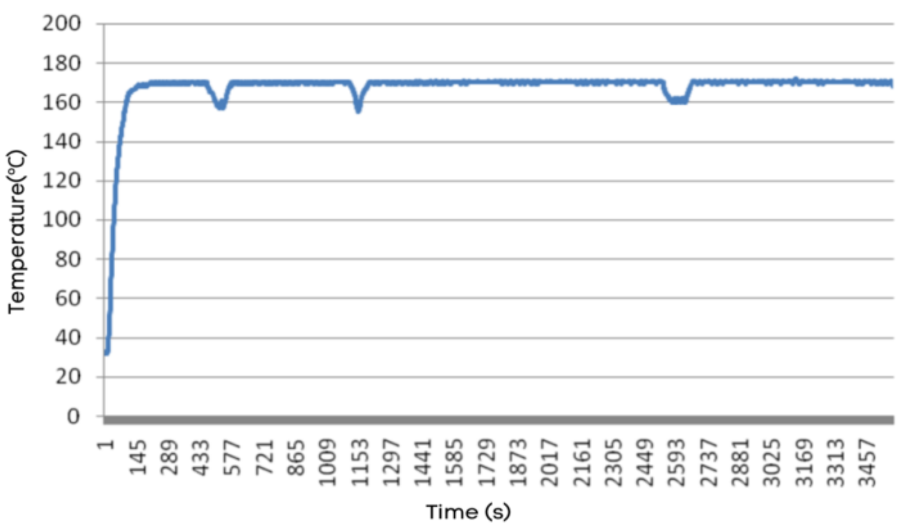


Figure 3.5. Test Results With Interference

Figure 3.6 shows the results of testing two controls, namely using on-off control and fuzzy logic control. Basically, the on-off control system is simpler than the control system that uses fuzzy logic.

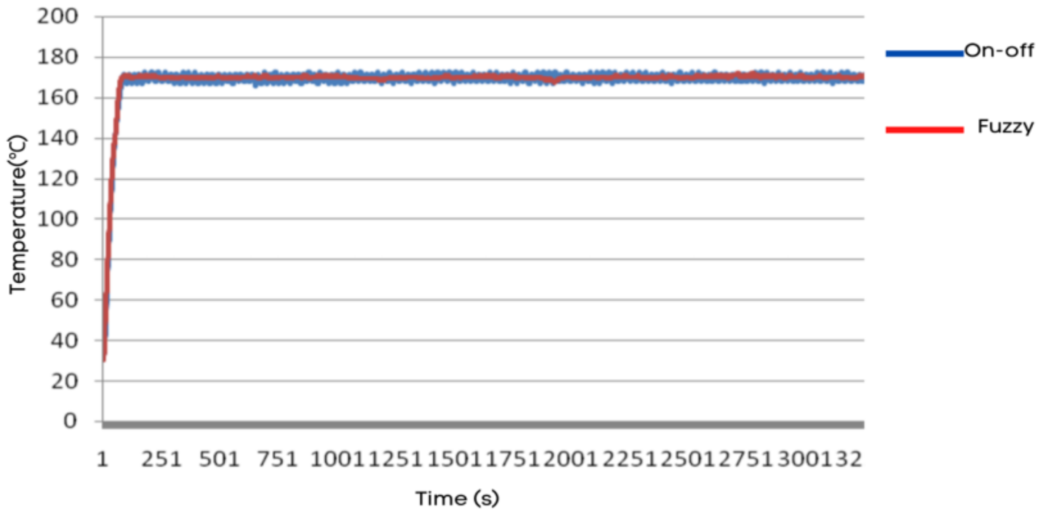


Figure 3.6 Comparison of fuzzy logic control with on-off control

The time required for the on-off control to reach the set point is 81 seconds, the same value for the control system using fuzzy logic. However, the results of controlling the on-off control system are not as stable as the results of controlling systems that use fuzzy logic. From the test results, it can be seen that the temperature controlled using fuzzy logic is more stable around the set point, which is 1700 C. The on-off control system is more responsive than the control system using fuzzy logic. When the temperature of the sterilization process reaches the set point, the on-off control system will immediately turn off the blower, even though the on-off control system has a larger overshoot than the control system that uses fuzzy logic. After the temperature of the sterilization process drops and is below the set point, the on-off control system turns on the blower again and the temperature will rise again until it reaches the set point. With the working principle of the on-off control system, the steady state error value is greater than that of the fuzzy logic control system.

V. Kesimpulan

This research has succeeded in designing a low-cost dry heat type of health equipment sterilizer using the Arduiono Uno microcontroller, sensor modules and fuzzy logic controllers. Evaluation of the performance of the controller was very good, this indicated by the highest overshoot value was 1.1%, the steady state error value was 1.1%, and the fastest rise time was 240 seconds.

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