FUZZY-BASED TEMPERATURE CONTROLLER FOR CULTURING MESOPHILIC AND THERMOPHILIC BACTERIAL USING FIRING ANGLE

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ABSTRACT

Temperature control is an important parameter in the fields of engineering and medical Laboratory. Culturing of micro bacteria and enzymes for the purpose of medical diagnoses or process development in manufacturing industries require their optimum temperature to be monitored and control. In this research work Fuzzy logic controller was designed to control the incubator Temperature, by computing appropriate firing angle. MATLAB Simulink toolbox was used for simulation. The results show that the fuzzy logic controller tracks the optimum Temperature for culturing Mesophilic and Thermophilic bacteria at 37.5ºC and 55.2ºC respectively. The transient response shows an overshot of 0.5% for the two responses. The rise time were 787ms and 792ms for 310.5 Kelvin and 328.2 Kelvin respectively. The settling time for the 310.5 Kelvin response was 1s; whereas it took 2s for the 328.2 Kelvin response to attain steady state.

KEYWORDS

Temperature, Bacteria, Thermophilic, Mesophilic, Fuzzy logic, & Firing Angle.

1. INTRODUCTION

Temperature control is a cardinal issue that affects human living as well as micro-bacterial survival in their natural habitation. Temperature is an essential physical quantity which is found in most application of home appliances, scientific laboratories equipment and industrial processes. Scientific processes such as chemical reactions, equipment manufacturing and process control also rely heavily on the stability of temperature at certain threshold in order to give optimum performance. The main issue in every temperature control strategy is to monitor and maintain temperature status of facilities [1].

Temperature variation is one of the most important stress factors for microorganism in their environment. For instance, a temperature increase induces the bacterial heat Shock response which allows cells to adapt and survive against the thermal stress conditions [2]. Most bacteria grow within a particular temperature range. The minimum growth temperature is the lowest temperature at which a particular bacterium can still grow, while the maximum growth temperature is the highest temperature at which a bacterium can still grow. The optimum growth temperature, however, is the temperature at which the bacterium grows at its highest rate. When an organism is grown below its optimum and above its minimum temperature, it grows much more slowly because the metabolic enzymes are performing inadequately for maximum growth

and the plasma membrane becomes rigid and unable to transport nutrients effectively. Likewise, when an organism is grown above its optimal temperature the metabolic enzymes start to denature and quickly become nonfunctional, which slows the growth and actually kills the organisms when the temperature is too elevated.

[2], observed that "living organisms contain many genes encoded in their DNA sequences. Each gene contains the information needed for the cell to produce a specific protein or enzyme required to carry out a particular biochemical function or to fulfil a particular cellular process. Factors such as pH, light, and temperature may cause certain genes to be "turned on" or to be "turned off" under certain conditions. In other words, although the gene is always present in the organism's DNA, a variety of stimulants or inhibitors may cause gene expression (the transcription of the gene DNA to produce mRNA) to start or stop, respectively [2]. Ultimately, if gene expression is turned off, the appropriate mRNA is not produced and translation will not occur. Since the corresponding proteins are not produced, the cellular function controlled by that gene stops and the gene is no longer expressed. There is therefore the need to operate at optimum temperature particularly in culturing thermophilic bacteria [1].

Growth of bacteria on the surface of the eggshells and penetration of those microbes into the egg may be affected by ambient environmental conditions, in particular temperature and humidity [3]. This mean that if the right temperature is not provided for incubation of eggs such eggs may be contaminated by bacterial and may never mature to produce chicks, thereby causing economic loss. The same is applicable to bacteria that aid fermentation processes [3].

Bacterial and microorganisms are identified from their host samples via a process called Culturing. Culturing involve conditioning of bacterial or microscopic organisms under certain temperature and other factors such as humidity, for a definite period of time in order to visualize certain trends in growth of any type of bacteria, and the rate of its multiplication in a sample. In medical diagnosis, it is absolutely necessary to detect accurately the organisms, or bacteria, that is responsible for any illness so as to administer the right medicine and the required dosage. This means that results of culture processes obtained from patient's samples must be precise. Incubators are very useful equipment for setting and controlling of temperature for variety of purposes which includes, warming of pre-matured babies and culturing of bacteria. Mesophilic bacteria are a class of bacteria whose growth temperature range from 20^0C to 45^0C with optimal temperature at 37^0C [4]. Thermophilic bacterial are those bacterial whose growth temperature range from 45^0C to 85^0C with optimal temperature at 55^0C [4].

The focus of this research work is to design and Simulate Fuzzy logic temperature controller (27 ^{0}C and 55 ^{0}C) for culturing Mesophilic and moderate thermophilic bacteria in a choice incubator by using firing angle technique.

2. SYSTEM DESCRIPTION

The system comprises of keypad, a controller, heating element, sensor, display, and incubator. Figure 1.1 present a simple block diagram of a temperature control system using fuzzy logic controller. The candidate controller was designed in MATLAB Simulink environment. Desired temperature (Td) is inputted through the keypad, and the display show both the desired (Td) and the Actual temperature (Ta). The fuzzy logic controller simply takes in error (e) and change in error (ce) as an input variable and then make use of the fuzzy set to modify the temperature. If the actual temperature is less than the desired temperature, the controller computealpha which is the control signal, so as to increase or reduce the temperature to the required setpoint.
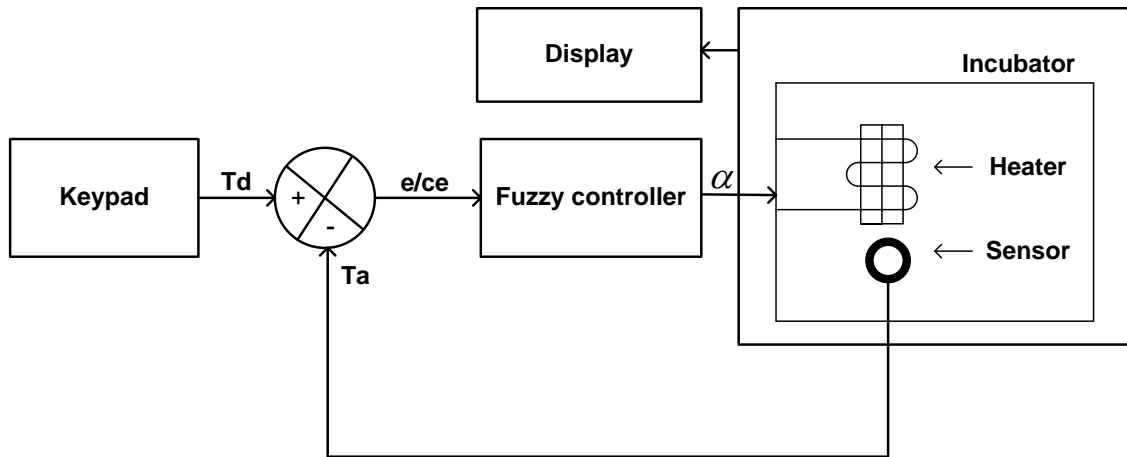
Figure 1. Simplified block diagram of a fuzzy Temperature control system

3. SYSTEM MODEL EQUATION

The incubator system is expected to draw power from an Alternating Current (AC) source with 240V and 50Hz peak voltage and frequency respectively. By Newton's law of cooling-

$$Q = h \, A \, (T_p - T_a) \tag{1}$$

Where Q = Convective heat transfer rate or local heat flux density (W)

      h = Convection heat transfer coefficient (W/M^{2}K)

      A = Surface area of object being heated or cooled (M^2)

      T_p = Surface Temperature of the object (K)

      T_a = Bulk Temperature of surrounding fluid (K)

Assuming there is negligible heat loss to the external environment;

$$P = I^2R = IV = V^2/R \tag{2}$$

Where P = Electrical power (W)

      R = Heater resistance (Ohms)

      I = Current (A)

      V = rms Voltage (V)

From (2) The Heat energy produced H can be represented as

$$H = I^2Rt \tag{3}$$

$$\frac{d}{dt}H = I^2R = \frac{V^2}{R} \tag{4}$$

Equating the two rates in (1) and (4)

$$\frac{V^2}{R} = h. \, A. \, \Delta T$$

$$\Delta T = \frac{V^2}{hAR} \quad (K) \tag{5}$$

Where ΔT is $T_p - T_a$

Equation (6) represents the Temperature difference or change in Temperature at any time.

Using a Triac as an actuator, the load Voltage across the heater is given by;

$$V_{rms} = \sqrt{\frac{1}{2\pi}\left(\int_\alpha^\pi V_M^2 \sin^2\theta + \int_{\pi+\alpha}^{2\pi} V_M^2 \sin^2\theta\right)d\theta} \tag{6}$$

$$V_{rms}^2 = \frac{V_M^2}{2\pi}\left((\pi-\alpha)+0.5\sin 2\alpha\right)$$

$$P = \frac{V_M^2}{2\pi R_L}\left((\pi-\alpha)+0.5\sin 2\alpha\right)$$

$$\Delta T = \frac{V_M^2}{2\pi R_L hA}\left((\pi-\alpha)+0.5\sin 2\alpha\right) \tag{7}$$

The actual Temperature (Ta) is therefore the summation of the change in Temperature and the ambient Temperature (initial temperature) in the incubator; taken as 27°C or 300K.

$$Ta = (\Delta T + 300)K \tag{8}$$

Substituting the following values into equation (7)

Vrms = 240V
R = 2 KΩ
A = 0.01 M²
h = 14 .4 W/M²K

Where A is the surface area of the heating element, and h is the coefficient of convective heat transfer.

Therefore,

$$Ta = 100 - 0.556\alpha + 0.278\sin 2\alpha + 300 \tag{9}$$

4. CONTROLLER DESIGN

4.1. Design of Fuzzy Logic Controller

In the design of a fuzzy controller, the items required are: the input to the controller, Fuzzification process, the knowledge base- which is the combination of the data base and the rule base, and Defuzzification of the output of the controller. The fuzzy controller shown in figure 1.2 accepts error E and rate of change in error CE as the input variables. These inputs are fuzzified in accordance with the membership function that is provided in the data base. The controller then applies the rules in the data base; and selects the ones that are applicable as a consequent to the antecedent under consideration at a time. The result, which is the consequent of the rules so fired, is reshaped by the application of appropriate implication method. The result of the implication

process is then aggregated and fuzzified into a single crisp value corresponding to the control action acting on the gain of the heater to either reduce or increase the temperature of the incubator.
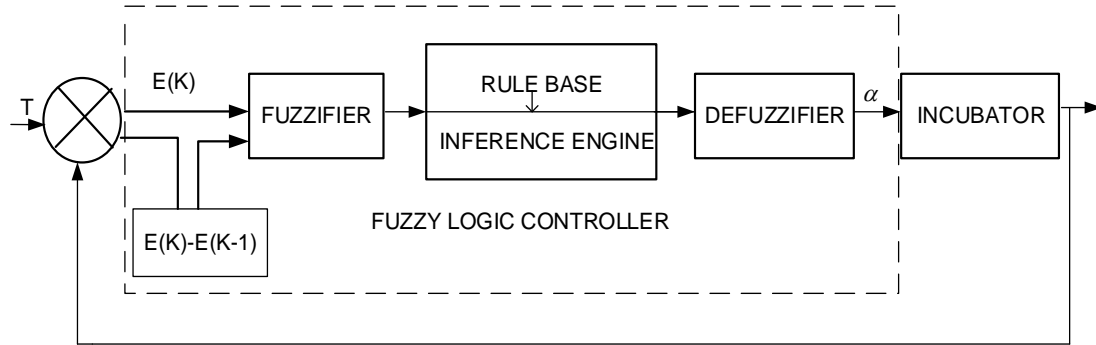

Figure 2. Fuzzy logic Controller in a closed loop system.

4.2.1. Fuzzification

Fuzzification is the process of converting crisp values of process variables into fuzzy sets. In this process, the universe of discourse is assigned boundaries (membership functions) in a manner similar to a universal set containing subsets of elements of the universal set [5]. The membership functions could overlap each other to a certain degree depending on the performance expectation of the controller designer. Figure 1.3 and Figure 1.4 show the membership function for the Fuzzification of input variables to the fuzzy controller, which are Error and change in error (CE) respectively.
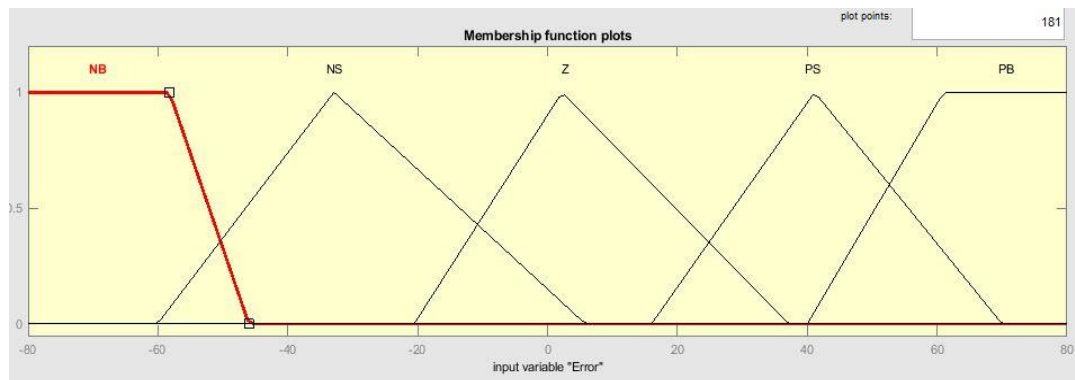

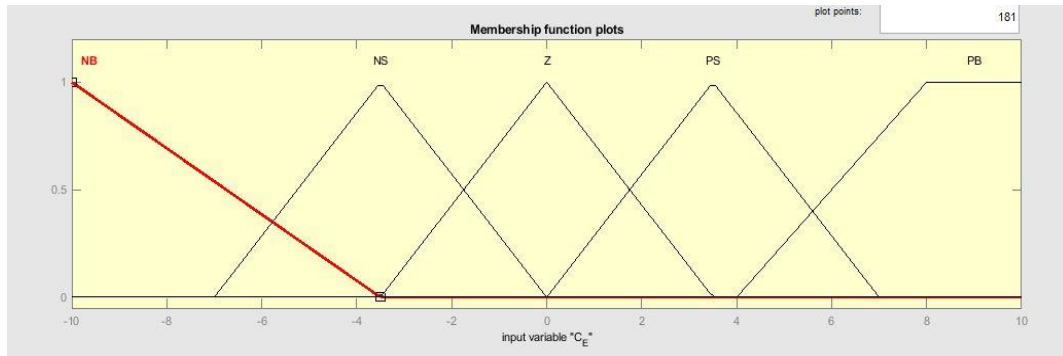Figure 3. Input membership function error (E)

Figure 4. Input membership function of change in error (CE)

4.2.2. Data Base

The data base is a store which provides relevant information that enables the controller to perform an operation. The information stored in the data base is: input variables, output variables, the universe of discourse for each variable, the demarcation of the universe of discourse into sub sets or fuzzy sets with or without overlap and the membership function assigned to each fuzzy set.

Considering the task of the Laboratory incubator whose range of temperature control is typically between the room temperature 30 degree Celsius and 60 degree Celsius, the universe of discourse for output variable is chosen to be between zero and 180 degrees. In addition, the output variable is assigned four (4) linguistic terms each representing a membership function as follows: very small (VS), Medium (MED), Small (S), Big (BIG), within domains [-59.59 57.3], [57.3 157.1], [14.3 120.3] and [120.3 234] respectively.

The universe of discourse for error is between [-80 80]; it has five (5) membership functions in domains represented as [-116 -46], [-60 5.83], [-20.56 14], [16 70] and [40 116]; carrying linguistic variables as: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) respectively. For the change in error, the universe of discourse lies between [-10 10], having five (5) membership function namely: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB) in the domains [-15 -3.5], [-7 0], [-3.5 3.5], [0 7] and [4 14] respectively. Figure 1.5 show the output membership function with the linguistic variables.
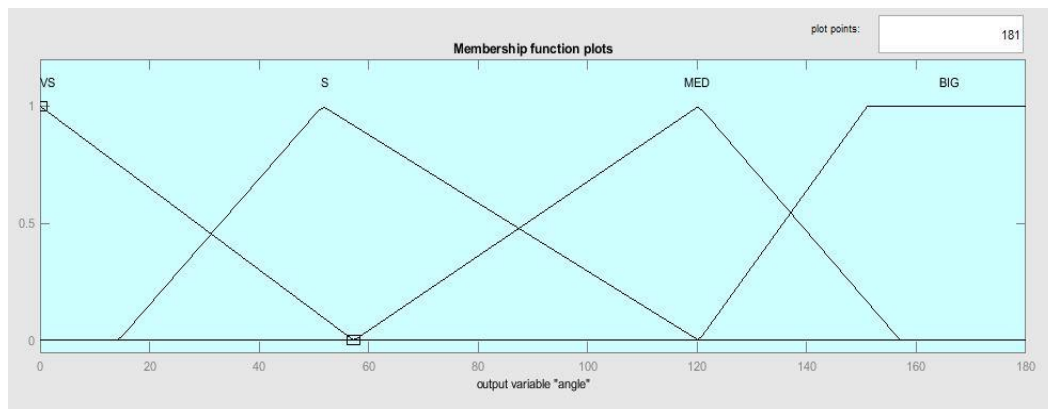

Figure 5. output membership function

4.2.3. Rule Base

In the operation of the fuzzy controller, the IF THEN rules are used to represent the antecedent and the consequent part respectively. The rules that govern the action of the fuzzy controller are summarized in Table 1.1

Table 1.1 The rule base for Input and Output variables of the controller

E/CE	NB	NS	Z	PS	PB
NB	VS	VS	MED	MED	BIG
NS	VS	VS	MED	S	BIG
Z	VS	S	S	BIG	BIG
PS	VS	MED	MED	MED	BIG
PB	VS	VS	VS	MED	BIG

4.2.4 Fuzzy Inference Engine

Instead of using mathematical formula, FLC uses fuzzy rules to make a decision and generate the control action. The rules are in the form of IF-THEN statements. Inference is used to compute the rules generated from the rule base[6]. Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model-based control techniques are impractical or impossible [7]. Fuzzy Logic deals with problems that have vagueness, uncertainty and uses membership functions with values varying between 0 and 1 [8],[9]. The inference engine instructs the controller on what action to take.

4.2.5. Defuzzification Method

This is a process by which all the aggregated fuzzy sets are transferred into a single crisp value necessary for the control action to take place [10]. There are various Defuzzification techniques but the centroid of area method (centre of Gravity) is used for this research work. Equation 10 describes the method of Defuzzification used.

$$\text{Dfz\_}\alpha = \frac{\sum_{i=1}^{k} Ai \times xi}{\sum_{i=1}^{k} Ai} \tag{10}$$

Where xi is a running point in a discrete universe of discourse and Ai is its membership value in the membership function.

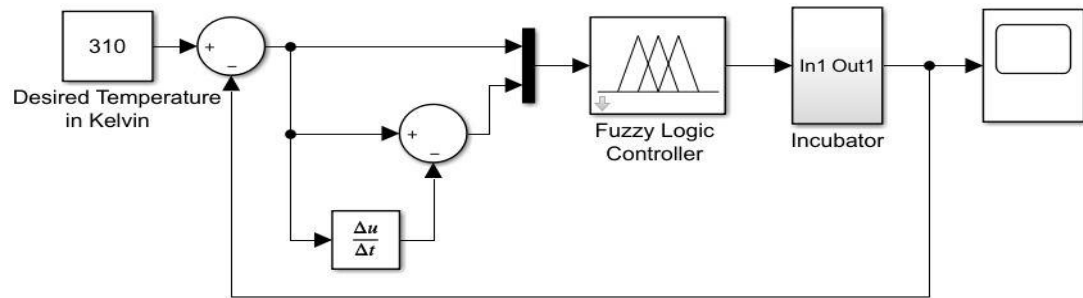## 4.2.6. Simulink Model of Fuzzy Logic and the Incubator System

Figure 6. Simulink model of the Fuzzy controller and a Laboratory Incubator.

4.2.7. fuzzy logic controller Flow Chart

The Algorithm for the temperature control for the laboratory incubator was design to follow the flow chart in figure 1.7. The system compares the desired temperature with the actual temperature of the incubator. Fuzzy logic controller then computes the error, change in error and finally the firing angle alpha that will drive the incubator temperature to the desired set point.
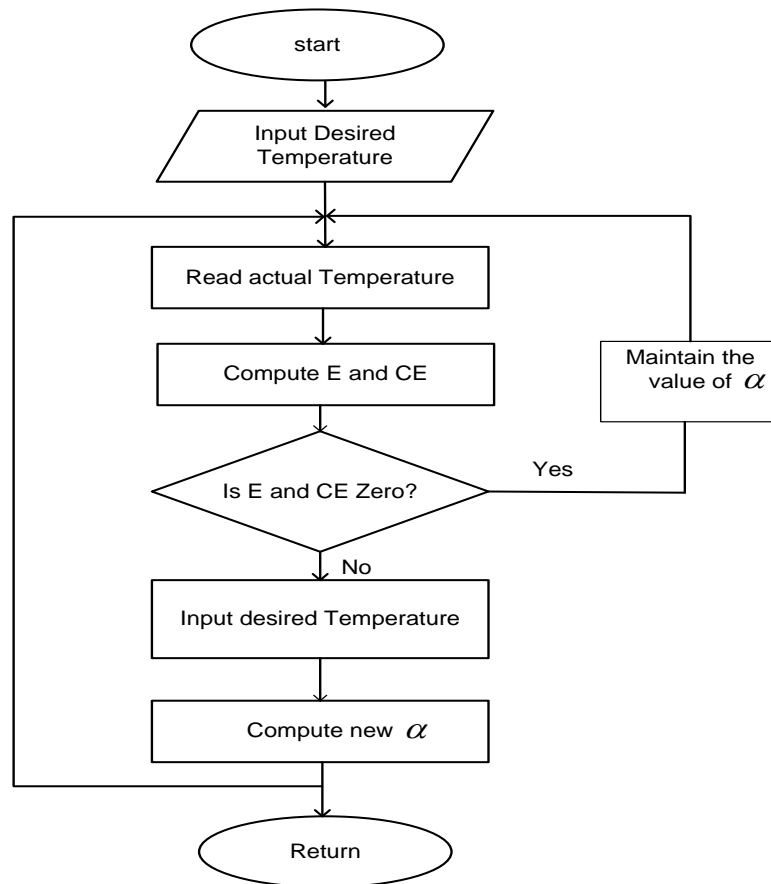

Figure 7. A flow chart for a fuzzy logic controller

5. RESULTS AND DISCUSSION

The simulation result obtained in MATLAB Simulink for the optimum growth temperature for culturing Mesophilic and moderate Thermophilic bacteria is presented in figure 1.8 and figure 1.9 respectively. From the simulation result, figure 1.8 represents the fuzzy logic controller response at 310 Kelvin (37^0C) set point; being the optimum growth temperature for culturing Mesophilic bacteria. Similarly, figure 1.9 gives the fuzzy logic controller response at 328 Kelvin (55^0C)set point, which is the optimum growth temperature for moderate Thermophilic bacteria. The response show that the controller tracks at 310.5 Kelvin and 328.2 Kelvin for the two set points. The controller was able to track the temperature at the desired range smoothly with minimal overshot (0.5%) for the two responses. The rise time were 787ms and 792ms for 310.5 Kelvin and 328.2 Kelvin respectively. The settling time for the 310.5 Kelvin response was 1s; whereas it took 2s for the 328.2 Kelvin response to attain steady state.
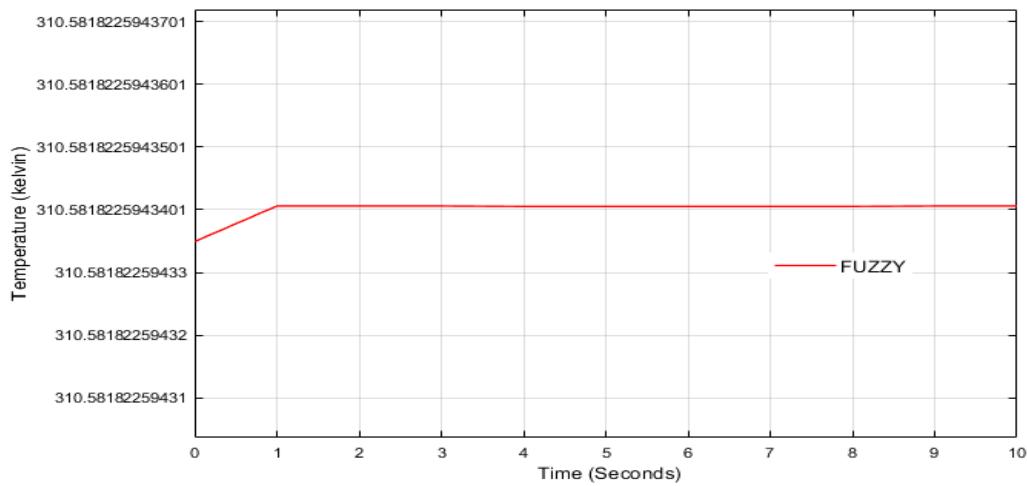

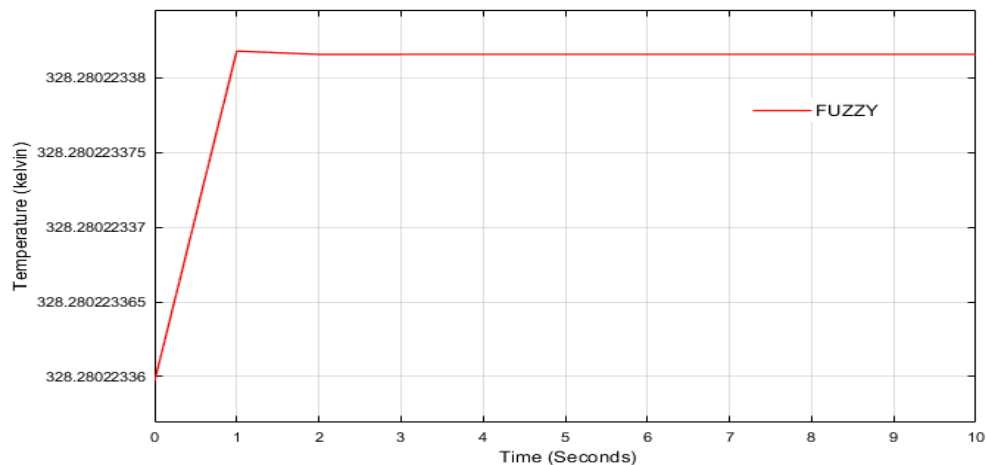Figure 8. A Response of Fuzzy controller at a Temperature of 310K

Figure 9. A response of Fuzzy controller at a temperature of 328K

6. CONCLUSION

A design of fuzzy-based temperature controller has been presented. The desired Temperatures required for optimum performance in the process of bacteria culturing with respect to Mesophilic and thermophilic bacteria were achieved with minimal offsets. The designed fuzzy-based temperature controller tracks the optimum temperature for culturing Mesophilic bacteria at 37.5^0C; and for the moderate Thermophilic bacteria at 55.2^0C respectively. The rise time were 787ms and 792ms for 310.5 Kelvin and 328.2 Kelvin respectively. The settling time for the 310.5 Kelvin response was 1s; whereas it took 2s for the 328.2 Kelvin response to attain steady state.

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