



Design and Development of a Smart, Electronic, Temperature-Controlled Food Warmer

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Abstract. This paper presents the design and development of a smart, electronic, temperature-controlled food warmer aimed at maintaining optimal food temperatures with precision and efficiency. The proposed system incorporates a Temperature sensor-based architecture to monitor and regulate the internal temperature using advanced sensors and heating elements. The system is designed with energy efficiency in mind, employing intelligent algorithms to minimize power consumption while ensuring uniform heating. Prototyping and experimental evaluations demonstrate the food warmer's capability to maintain temperatures within $\pm 2^{\circ}\text{C}$ of the desired set point, ensuring food quality and safety. This smart appliance is intended for both domestic and commercial use, offering a convenient solution for temperature-sensitive food storage and serving applications.

1. Introduction

In today's fast-paced lifestyle, maintaining food at optimal serving temperatures while preserving its quality and freshness is a challenge faced in various settings, including homes, restaurants, and food delivery systems. Traditional food warming methods often result in uneven heating, energy inefficiencies,

and degradation of nutritional value. The development of smart, electronic, temperature-controlled food warmers presents a modern solution to these challenges, leveraging advancements in sensors, microcontrollers, and user-interface technologies (Bogdanovs et al., 2019).

This paper explores the design and development of a smart food warmer that integrates temperature sensors, intelligent control algorithms, and an intuitive interface to ensure precise temperature regulation (Gao, 2023). The proposed system not only improves food safety and quality but also enhances energy efficiency and user convenience. By employing innovative design principles and incorporating feedback from end-users, this study aims to contribute to the growing field of smart kitchen technologies and pave the way for further advancements in food preservation and service (Samath et al., 2022).

2. Design Analysis

This section deals with the mathematical analysis and calculations which led to the choice of the various components used for the project.

The design process strictly follows the method outlined by the block diagram in chapter one which consist of five stages and each stage was carefully designed to ensure that it could function as a standalone device and to provide a structured way to deal with the system components, which later come together to form a whole circuit of the temperature control food warmer.

This project (temperature control food warmer) consists of the following stages which include:

- Power supply
- Battery control
- Temperature Control
- Heating element control
- Thermal system

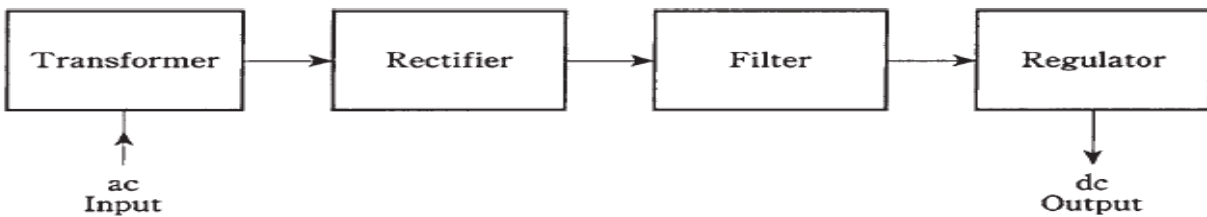


Figure 1: Block diagram of an AC to DC power supply

2.2.2 The power transformer

The transformer used here, is a step-down transformer since the output or the secondary voltage of a step-down transformer is lower than the input or primary voltage. The consideration for the size of transformer used was calculated to match the needed output voltage of the device. Since the step down transformer used is 250VA AC/ 14V DC(Liu, 2011). The peak voltage from the secondary windings is calculated as follows:

$$\text{Peak voltage} = V_{rms}\sqrt{2} \tag{1}$$

Since the $V_{rms} = 14V$

Peak voltage= $14V \times \sqrt{2} = 19.8V$ (Mbamaluikem et al., 2022).

2.2.3 Rectification

Since the two important features of a power-supply diode are the average forward current (I_o) rating and the peak inverse voltage (PIV) rating, here full wave bridge rectifier which has a maximum forward current of 1A and a maximum peak reverse voltage of 600V (1N4001) was used to make the conversion of the peak inverse voltage (i.e. 19.8V AC) into a DC voltage. And since the rectifier drawn 0.7V from the voltage in the positive and negative half cycle respectively, then 1.4 V was finally taken from the peak voltage at full wave. Therefore, the output voltage from the rectifier is then taken as:

2.1 Power Supply

The device is powered by a DC voltage which could be obtained from either the battery or from the AC power source rectified to give the DC voltage required. Here both methods were implemented in other to have alternative source of power, should in case there is power outage.

2.2.1 A.C Regulated Power Source

Most of the electronic devices and circuits require a dc source for their operation, and this was implemented by rectification with an appropriate filtering and voltage regulation. Figure 1 present the block diagram of Dc power supply.

Output voltage from the rectifier = peak inverse voltage – diode forward voltage

$$\text{Output voltage from the rectifier} = 19.8V - (1.4 \times \sqrt{2}) V = 17.8V \text{ (By \& Planning, 2015).}$$

2.2.4 The bridge rectifier

The average dc output voltage in the bridge circuit is 90 per cent of the rms ac input voltage. The PIV across the diodes is 1.4 times the rms ac input voltage

$$\begin{aligned} \text{Through rectification} &= \text{transformer voltage} - 1.4 \\ &= 14 - 1.4 = 12.6V \end{aligned}$$

By apply capacitor = $\sqrt{2} \times 12.6 = 17.8V$

Therefore, 17.8V will be regulate to 14.4V to charge the battery

Two bridge rectifiers are used in the project, one is used for battery charging circuit and the other is for heating element. It will deliver 10Amp.

2.2.5 The filter capacitor

Pulsating dc comes straight from a rectifier. The ripple in the waveform must be smoothed out, so that pure, battery is supplied. The filter does this.

Capacitor of 6800 μ F at 50V is used in the project, connected in parallel with the rectifier output. Electrolytic capacitors are almost always used. They are polarized; they must be hooked up in the right direction. it is used for the smoothing of the AC. The lower the load resistance, the faster the filter capacitors will discharge. Larger capacitances hold charge for a

longer time with a given load. The choice of the capacitor used is calculated using equation 2 (Udawat et al., 2023).

The choice of the capacitor used is calculated using the formula presented in equation (2)

$$Q = CV \tag{2}$$

$$Q = It$$

Since, $t = 1/f$

$$C = \frac{1}{V_{pp\ ripple} f_r} \tag{3}$$

(3)

Where,

C = the capacitance of a capacitor,

I = maximum output current from the transformer = $12,000 \times 10^{-3} A$

$V_{pp\ ripple}$ = maximum peak to peak ripple voltage = 1V

f_r = ripple frequency = (2f for full wave frequency = $2 \times 100 = 200 Hz$)

$$C = \frac{12,000 \times 10^{-3} A}{6,500 \mu F \times 200} = 6,500 \times 10^{-6} F = 6,500 \mu F$$

Here, 6,800µF rated capacitor is used, since 6,500µF does not exist in the market.

Filter capacitors work to keep the dc voltage at its peak level. This is easier to do with the output of a full-wave rectifier as compared with a half-wave circuit. The remaining waveform bumps are the ripple. With a half-wave rectifier, this ripple has the same frequency as the ac, or 60 Hz. With a full-wave supply, the ripple is 120 Hz. The capacitor gets recharged twice as often with a full-wave rectifier, as compared with a half-wave rectifier.

2.2.6 Switch: Switch is used in series with the fuse which control the incoming current, ON/OFF

2.2.7 Fuse: it is used to protect the circuit if there is internal fault, in event it draw high current due to over voltage or fault in the system.

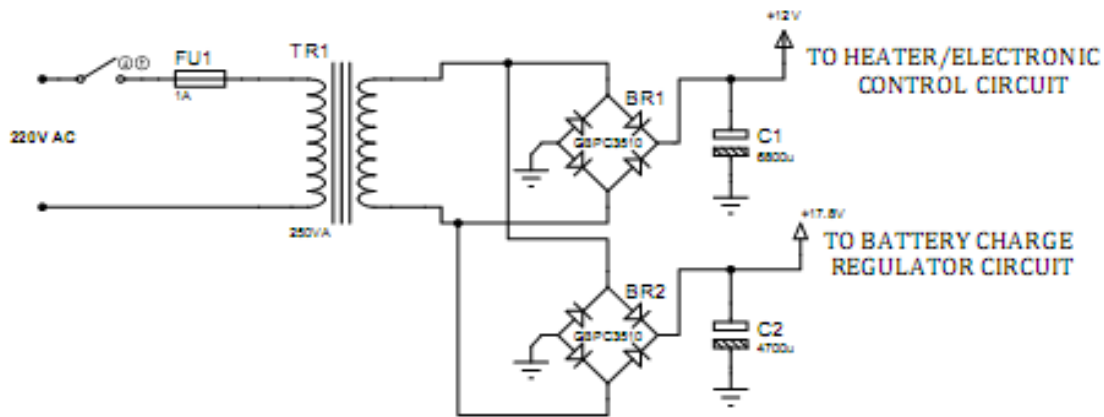


Figure 2: Power Supply Circuit

2.3 Battery Charging control

Here, 12V DC battery is used as a backup energy source for the temperature control food warmer device which passed through an appropriate voltage regulator IC LM7815 in order to regulate the battery voltage, should in case there is an overvoltage from the battery.

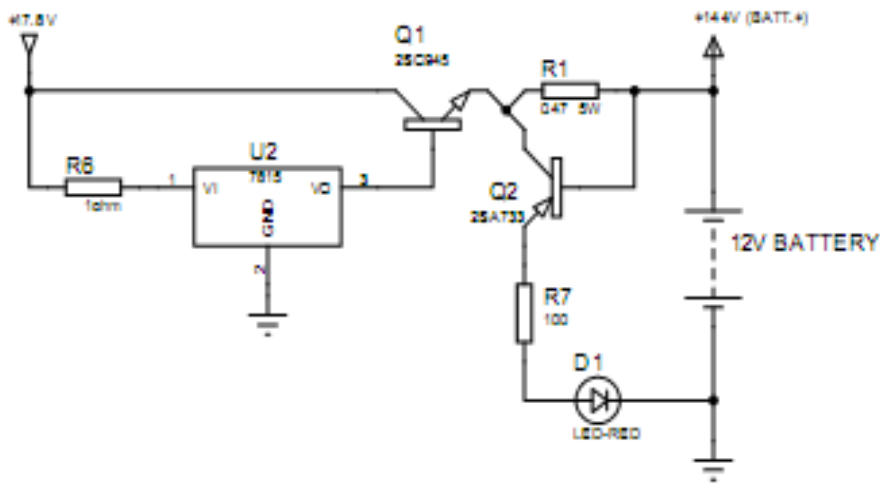


Figure 3: Charging circuit

From the circuit above used in the design of temperature control food warmer, the below components was used. Regulator: The regulator of IC LM7815 is used in the project. It is used to stabilize the voltage to 15V for the transistor (power regulator) to bring out 14.4V, and then it will charge the battery. Transistor: the transistor with the identification number 2SC945 was used, which can handle 15A is used in the design. Resistor: resistor of 1ohm is used in the project, which is used for limiting the current from the source to the regulator(Hund, n.d.).

2.3.1 Low level battery control

Low level control is design in the project to known if the backup battery is getting low in order to avoid running down of the battery.

From the circuit above used in the design of temperature control food warmer, the below components was used.

Resistor: resistor of 2.7kΩ is used. The resistor will limit the current to the Zener Diode.

zener Diode: 5.6V (zener voltage) which is used to break down to certain voltage. If the voltage is higher than the zener voltage. It stabilizes the voltage to certain voltage.

Diode: used to clamp down the voltage to 0.7V so that at any time current is being drawn.

Transistor: 2SC945 is used. The transistor here acts as a switch.

Biasing resistor: 100Ω is used. It biased the transistor.

Transistor: 2SC733 is used in the project to supply the relay.

Capacitor: the capacitor of 1μF is used in the project to set the given solid switch off timing or disconnection timing.

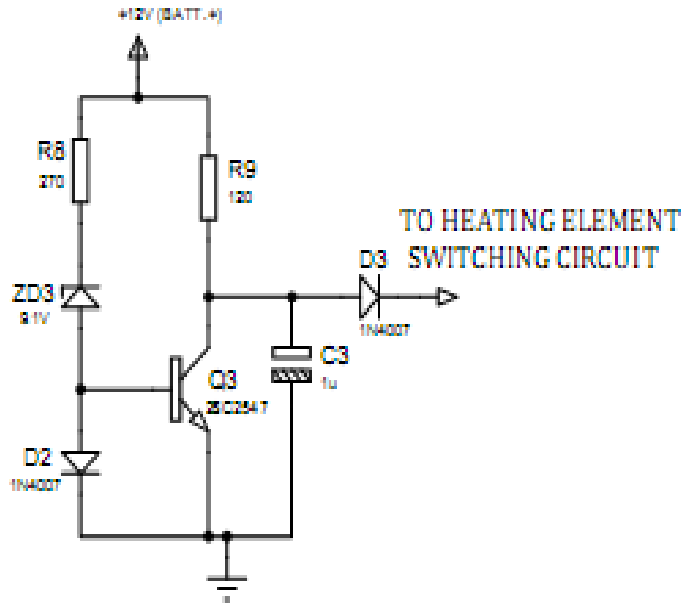


Figure 4: battery Low level control circuit

2.4 Temperature Control

Temperature is the degree of hotness of a substance or object as used in the design of this project. The higher the temperature, the shorter a heater’s service life. Thermistors are best for temperature applications with limited temperature ranges. Nichrome heater elements changes resistance less than two times in their operating temperature ranges(Nyiekaa & Francis, 2021).

2.4.1: Thermistor

In choosing the use of a thermistor, it’s important to be sure the applications are within its temperature limits. Inside their application ranges, thermistors exhibits a great change in resistance for a relatively small change in temperature.it as both positive and negative temperature coefficient but a negative temperature resistance coefficient is used in this project. Thermistor which is also called temperature sensor TTF -103. As the temperature increases, resistance decreases(Barriere, 2017).

2.4.2 Indicator

Light emitting diode is used in this project to be able to indicate when the heater is ON, and since LED can be damaged if high current is allow passing through it, so, resistor is connected in series with the LED for protection.

The LED resistance can be calculated below using ohms law

$$V = IR \tag{4}$$

$$R = V / I$$

$$V_{cc} = V_d + I_d$$

Where V_d = voltage drop across the diode which is 2.2V

I_d = LED forward current = 5mA

And supply voltage (V) = 12V

$$R = \frac{\text{supply voltage} - \text{voltage drop across the LED}}{\text{LED Forward current}} \tag{5}$$

$$R = \frac{12 - 2.2}{5 \times 10^{-3}}$$

$$R = 1960\Omega = 1.9K\Omega$$

Therefore, available market value of 1.8KΩ resistor is used for the LED indication.

2.4.3 Comparator

The comparator of LM393 is used to sense the temperature. Also use to cut OFF at desired temperature and cut IN back at lower temperature. Comparator and thermistor works together to sense the temperature ON/OFF. Comparator with the sensor may also act as the thermostat. The transistor used here to drives the relay.

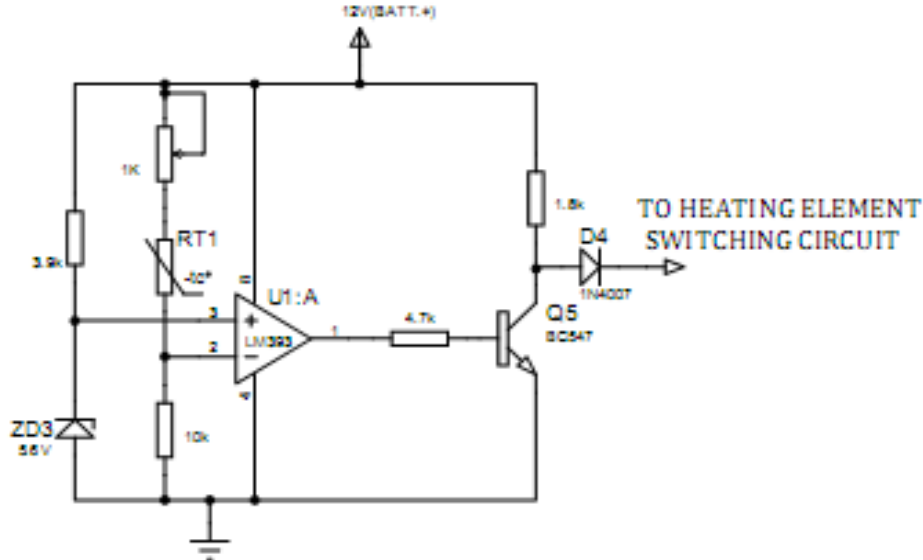


Figure 5: Temperature control circuit

2.5 Heating Element

Nichrome wire heating element is used in the project which as a tape surface (coiled element). The heating element is energy efficient and quick to heat to the desire temperature. The rated power is 100W at 12V in 8places (radial). The heating element is placed around the bowl It as upper and lower parts, which control 50W at round(Mauliddiyah, 2021).

$$\text{Current demand by the heating element, } I = \frac{100}{12} = 8.33\text{A}$$

$$\text{Current demand by each element} = \frac{8.33}{8} = 1.04\text{A}$$

The placement of heater coil is to be at equal displacement (distance radial) to each other. The eight coils are to be connected in parallel and be controlled by an electronic circuit.

2.5.1 Calculation on the linear resistance of a length of tape

To perform as a heating element the tape must resist the flow of electricity. This resistance converts the electrical energy into heat which is related to the electrical resistivity of the metal, and is defined as the resistance of a unit length of unit cross-sectional area. The linear resistance of a length of tape is calculated from its electrical resistivity as follows.

Each element coil is 32.5cm long

Tape width $b = 0.050205\text{mm}$

Tape thickness $t = 0.000525\text{mm}$

$$a = t \times (b - t) + (0.786 \times t^2)$$

$$= 0.000525 (0.050205 - 0.000525) + (0.786 \times 0.000525^2)$$

$$a = 2.63 \times 10^{-5} \text{mm}^2$$

the linear resistivity of the coil, from equation 2.2.

$$R = \frac{\rho \times l}{a} \times 0.01(\text{ohms}) \tag{6}$$

$$R = (1.11 \times 10^{-6} \Omega \cdot \text{m}) \times 32.5\text{m} \times 0.01$$

$$= \frac{2.63 \times 10^{-5} \text{mm}^2}{13.72 \Omega}$$

As a heating element, tape offers a large surface area and therefore, a greater effective heat radiation in a preferred direction making it ideal for design of temperature control food warmer.

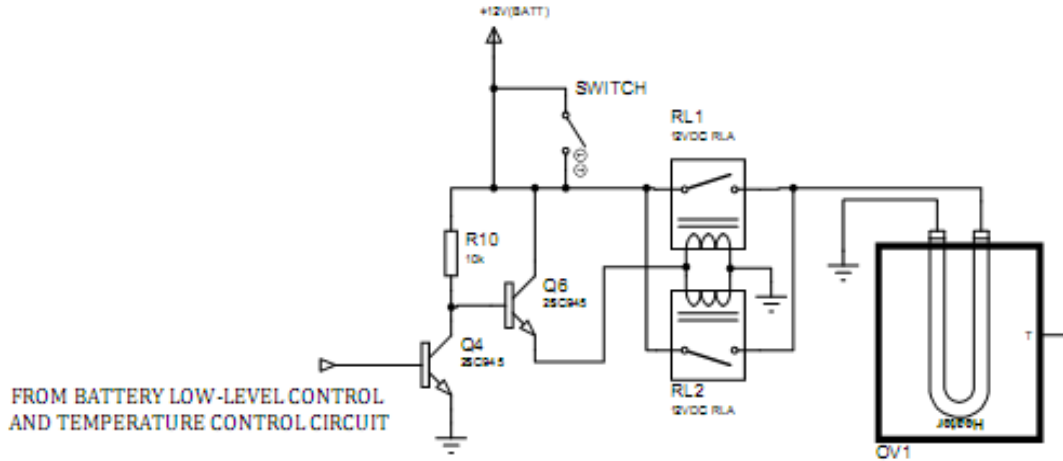


Figure 6: Heating element control circuit

2.5.2 Switch Relay

The switch here is a manual switch of 10A, Intentional switching OFF/ON the heating element. The two switches in the relay are connected in series.

The electromagnetic relay is a long-life hybrid relay that uses a mechanical relay with a triac in parallel with the contacts to turn ON and OFF the load at the zero-cross point in the sine wave. Once the triac has turned ON the load for one cycle, the mechanical relay is energized to pass the current until the turn OFF sequence when the triac again turns ON for one cycle and then turns OFF at zero cross. Relay of 10A, 12V is used, to give electric control to pass current to the heater. Also, it will switch ON/OFF the power to the heating element.

2.6 Thermal System

A thermal system is typically made up of a work load, heater, temperature controller and temperature sensor (thermistor) in the construction of this project. Figure 3.10 shows a simple food heating application using all parts of the thermal system involve in the construction of this project. The work load is the food being heated. The sensor is immersed directly into the stainless bowl so it can accurately sense food temperature. The temperature control is controlling the food temperature by adding heat as necessary. The heater, of Course, is providing the heat required to heat the food. The each part plays a vital role in the heating system(Reese et al., 2008).

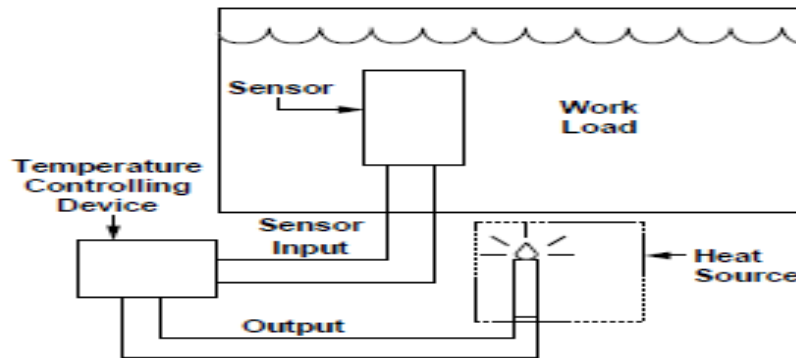


Figure 7: Thermal system parts applied-food heating

2.6.1 Thermal System Components

The main components of the thermal system used in this project include
 work load,
 heat source,
 heat transfer medium and
 temperature controlling device(s)

Work load: The work load is that which must be heated.

Heat source: The heat source is the device which delivers heat to the system.

Heat transfer medium: The heat transfer medium is the material (a solid, liquid or gas) through which the heat flows from the heat source to the work.

Temperature controlling device(s): The temperature controlling device directs its output to add, subtract, or maintain heat by switching heaters or cooling apparatus ON and OFF. The controlling system usually includes sensory feedback.

2.6.2 Thermal System Process

The sensor, controller and heater work together as a "team" to heat and control work load (food) temperature in this project. The process is as follows:

When the thermal system is switched on, the sensor senses food temperature and sends the signal to the temperature control.

The controller compares actual temperature to set point (or desired) temperature. The food temperature may be below the set point, so the controller switches on the heater.

The heater raises work load temperature. The sensor is continuously feeding a signal to the controller to keep it informed of food temperature changes.

At some point, the food temperature reaches set point temperature. The controller, sensing this, switches the heater off. Now the controller will switch the heater on and off as needed to maintain set point temperature (or desired).

Then, food now serves as the heat transfer medium from heater to metal part. The cold metal part begins absorbing heat energy from the food, causing food temperature to decrease.

The sensor tells the control that food temperature is dropping. The controller compares actual and set point temperatures. It decides to switch on the heater (Mohammed et al., 2008).

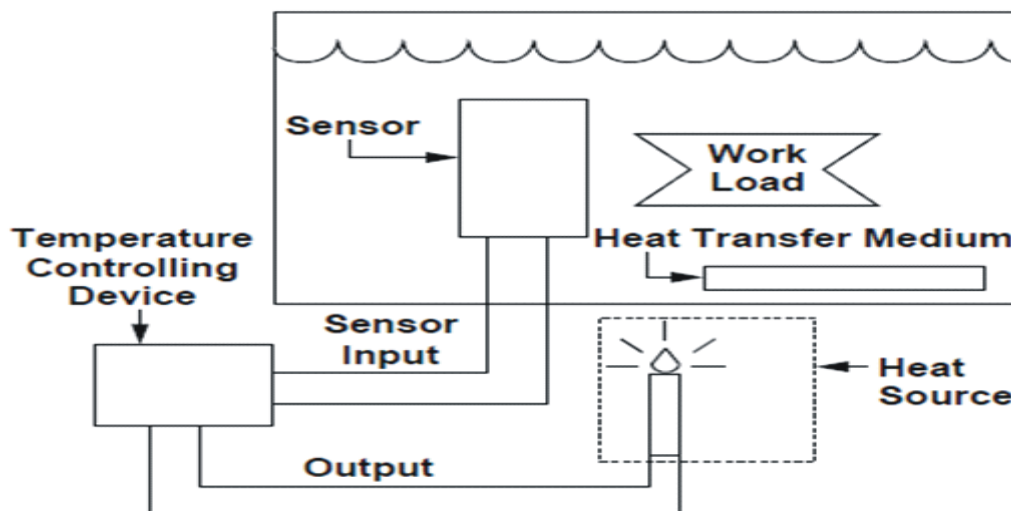


Figure 8: Thermal System Process

2.6.3 Selection of a temperature controller

The selection of a temperature controller is determined first of all by the degree of controllability required. It's best to select the temperature controller type and model that will give the optimum control needed to achieve desired results. I'll want to avoid selecting more control than is required.

There are a variety of control modes that provide differing degrees of controllability. The ON-OFF mode is used in the project. The operation of the ON-OFF control is just as the name implies; the output device turns full ON or it turns full OFF when reaching set point. Temperature sensitivity is designed into the control action between the ON and OFF switching points. This temperature sensitivity is established to prevent switching the output device ON and OFF within a temperature span that is too narrow. Switching repeatedly within such a narrow span will create a condition known as output "chattering" (intermittent, rapid switching). Temperature is always controlled "about set point." This is dictated by the switching hysteresis (also sensitivity or switching differential) of the ON OFF control. The control action further dictates that there will always be a certain amount of temperature overshoot and undershoot. The degree of overshoot and undershoot will be dependent on the characteristics of the entire thermal system(Mukherjee & Sivaniranjan, 2016).

2.6.4 Thermal Control Principle

The type of thermal control principle used in the design of a temperature control food warmer is a closed loop control. The closed loop, or automatic, controller uses feedback information from the sensor to properly regulate the system. As process temperature changes, the feedback loop provides up-to-date status information that allows the controlling device to make self-correcting adjustments. The closed loop control device is a much more desirable approach to temperature control.

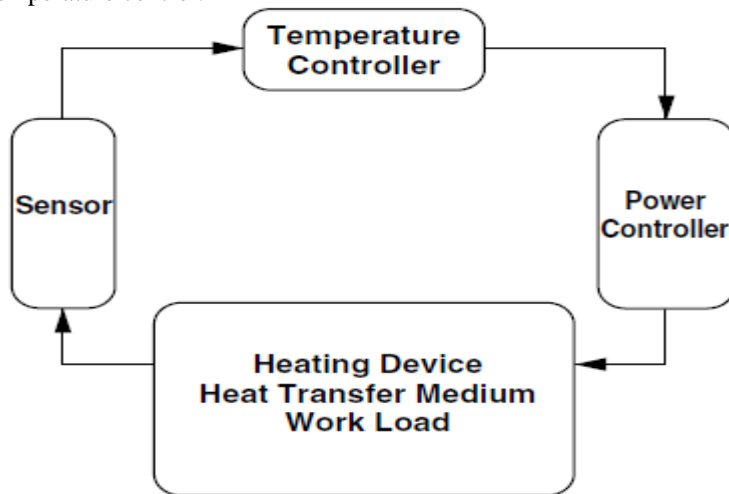


Figure 9: Closed Loop Control

2.6.5 Sensor placement

Placement of the sensor in relationship to the work load and heat source can compensate for various types of energy demands from the work load. Sensor placement limits the effects of thermal lags in the heat transfer process. The controller can only respond to the temperature changes it through feedback from the sensor location. Thus, sensor placement will influence the ability of the controller to regulate the temperature about a desired set point.

2.6.6 Sensor in a Static System

Static sensor used in the design of a temperature control food warmer. Static system occurs when there is slow thermal response from the heat source, slow thermal transfer and minimal changes in the work load. When the system is static, placing the sensor closer to the heat source will keep the heat fairly constant throughout the process. In this type of system, the distance between the heat source and the sensor is small (minimal thermal lag); therefore, the heat source

will cycle frequently, reducing the potential for overshoot and undershoot at the work load. With the sensor placed at or near the heat source, it can quickly sense temperature changes, thus maintaining tight control.

2.6.7 Energy needed to supply

$$A = U \times I \times t \quad (7)$$

Voltage, $U = 12V$

Power rating for heating element = 100W at 12V

Heating element required current, $I = \frac{100}{12} = 8.33A$

Therefore, energy needed to supplied, $A = 12 \times 8.33 \times t$

Time required, t will be varied depending on the quality of food and the type of food.

2.6.8 To determine the amount of heat required to raise the temperature

From the equation 2.7,

$$Q_n = C \times m \times (t_{\text{final}} - t) \text{ where } t < 50^\circ\text{C} \quad (8)$$

Mass m will be variable because the food content will vary

Heat capacity C will also vary from one food to another

Desired temperature t_{final} will be 50°C

Time required t will vary depending on the quality of the food and food temperature

Therefore, Heat supply, Q_n will be variable subject to food level and food temperature.

2.6.9 Principle of operation

When a heater is connected to an electric power supply, electricity flows through the resistance wire. The wire resists the flow of electric current through it. This converts electrical energy into heat energy, causing the resistance element to get very hot. After the controller receives the sensor signal, it compares the actual load temperature to the desired temperature (called set point). If the workloads (food) temperature gets too high, the heater is switched off. If the work load temperature drops too low, the heater is switched on. This "on/off" switching regulates electric current to the heater and thus work load temperature.

2.6.10 complete circuit of the temperature control food warmer

All the sections explained above such as: the power supply section, battery control section, temperature control section, the heating element section and the thermal section are put together to make up the circuit diagram of a temperature control food warmer used in the designing of the project. The diagram shown below is a full circuit diagram of a temperature control food warmer.

3.1 System Development

The heating element is attached to the aluminium plate which is insulated and placed on the stainless steel. The heat is being transmitted through the aluminium plate and stainless steel. Which is now bolted together to make sure that the aluminium plate and the stainless steel is firmly attached. The warming unit is now placed in the outer case of the temperature control food warmer which is made up of a plastic container.

First, the main assembly is the heater band which is later placed on the stainless steel. Next, the temperature sensor is placed at the bottom centre on the stainless steel.

The circuit that produces the voltage required to operate the warmer consists of a large transformer, a high voltage rectifier and a filtered capacitor. All of these components are mounted together to supply power to the temperature control food warmer.

3.2 Testing and packaging the temperature control food warmer

The power from the power supply is routed through the control section to the heating elements. Then, the warming unit began to heat up and the sensor senses the warming unit temperature and sends the signal to the controller. The controller cuts off the heater since the desired temperature has been reached. The food warmer runs for 3-4 hours continuously as part of the testing process. After testing is complete, several data points of the temperature control food warmer were taken, and the temperature control food warmer was packaged. This completes the design process.

3.3 Temperature control food warmer challenges

There were still problems to overcome before the temperature control food warmer could be used. Before we could get the mechanical materials used in this project such as the heating element, mica sheath and the insulation these materials were selling at a high price. Thus, we developed new standards and required changes in the construction of the temperature control food warmer so as to meet up with the target. Still, we could not meet up with the market price because of those components.

3.4 Effect on food and nutrients

Several experiments have shown that if properly used, the temperature control food warmer does not change the nutrient content of foods, and there is a tendency towards greater retention of many micronutrients with temperature control food warming, probably due to the shorter preparation time.

The temperature control food warmer will only keep the food warm at 50°C. Any form of cooking will destroy some nutrients in food, but the key variables are how much water is used in the cooking, how long the food is cooked, and at what temperature.

3.5 The results from the sample experiment

Due to data taken from the experiment, the results are represented in graph style. The actual result data are available in table 4.1. There will be one graph of food temperatures against time taken to reach the desired temperature and time to maintain 50°C.

3.5.1 Experiment

Type of food - Beans

Size of food - 1.2kg

Time - 35mins

Table 4.1: Beans Replication

Temperature (°C)	Time Taken to reach 50°C, T _{D,T} (min)	Recycling time, T _{R,C} (min)
0	2.00	
1	2.20	
2	2.50	
3	3.90	
4	4.50	
5	5.00	
6	5.10	
7	5.50	
8	5.70	
9	6.50	
10	8.00	
11	10.50	
12	13.00	
13	15.20	
14	16.50	
15	17.00	
16	18.00	
17	19.10	
18	19.30	
19	20.00	
20	20.20	
21	22.40	
22	22.50	
23	22.70	
24	23.10	
25	29.00	
26	29.50	
27	20.00	
28	25.50	
29	26.20	
30	26.50	
31	27.00	
32	27.50	
33	28.00	
34	29.00	
35	20.00	57.00
36	20.90	55.00
37	22.00	54.10
38	22.50	54.00
39	23.20	53.30
40	25.00	52.20
41	26.30	52.00
42	28.00	50.50
43	28.90	48.00
44	30.00	47.00
45	30.10	44.50
46	32.50	40.00
47	33.40	39.00
48	34.00	38.40
49	34.90	38.00
50	35.00	36.00

Note: T_{D,T} is Time Taken to reach desire temperature 50°C, T_{R,C} is the Recycling time, (min)

3.5.2: Discussion

The time taken to reach the desire temperature will be vary from one food to the other depending on the quality(mass) of the food will want to keep warm.

It takes 35min before beans can reach the desire temperature and also maintain the temperature of the food for another 15min.the controller cut OFF the heater another 22min and the sensor sense the temperature level and sense the signal to the controller, later ON the heater at 35°C so as to make sure that the food is maintain at 50°C.

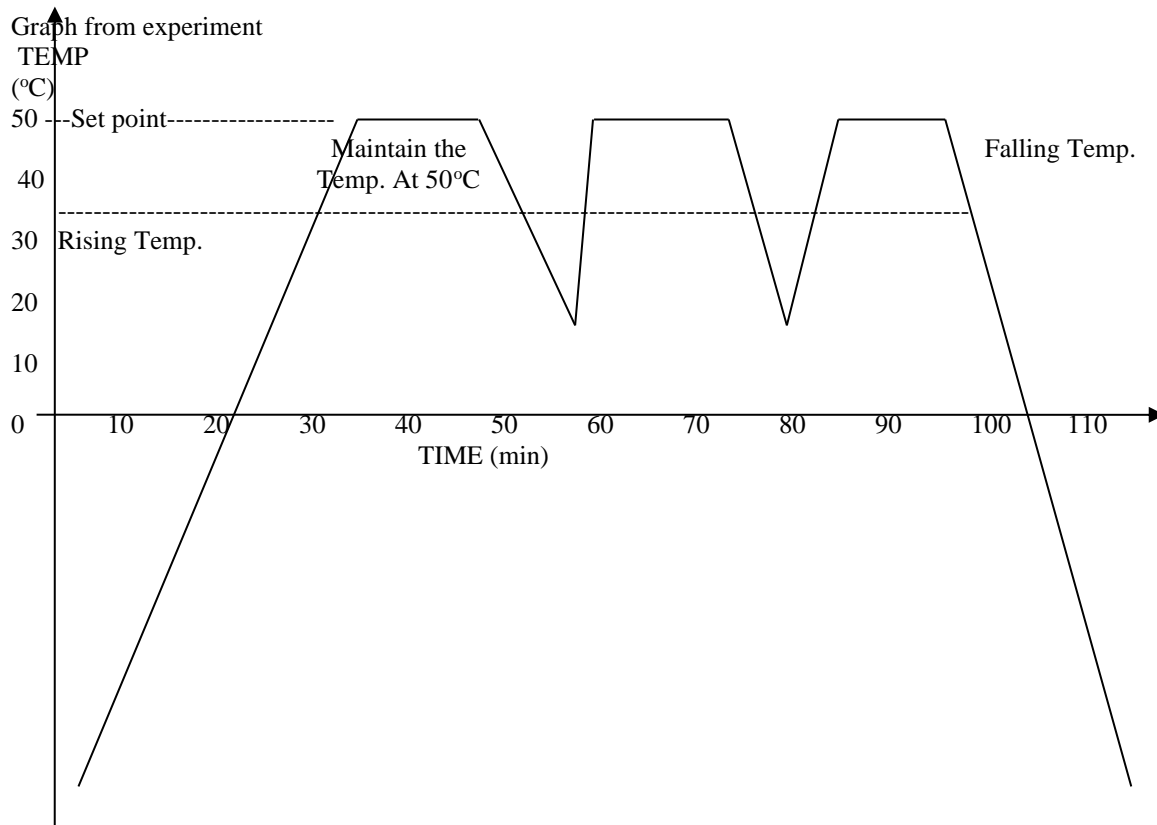


Fig.4.1 Graph of Temperature changes (°C) versus Time (min)

4. Conclusion

The design and development of a smart, electronic, temperature-controlled food warmer demonstrate the potential of integrating modern technology to enhance food storage and consumption experiences. By employing advanced temperature sensors, microcontroller-based control systems, and user-friendly interfaces, the device ensures optimal food temperature, thereby improving convenience and reducing food spoilage. The study highlights the importance of energy efficiency and user-centric design in creating practical solutions for everyday challenges. Future work may focus on improving the portability, energy source flexibility, and smart connectivity features to cater to diverse user needs and evolving technological trends. This innovation paves the way for smarter, sustainable food management solutions in domestic and commercial settings.

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