THE DESIGN AND FABRICATION OF A PORTABLE SYSTEM CAPABLE OF REHEATING FOOD AND MAINTAINING ITS TEMPERATURE

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SUBMITTED ON

TUESDAY 26TH SEPTEMBER, 2023

CERTIFICATION

This is to certify that the project work titled "**DESIGN AND FABRICATION OF A PORTABLE SYSTEM CAPABLE OF REHEATING FOOD AND MAINTAINING ITS TEMPERATURE**" was carried out by

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DEDICATION

This project is dedicated to our Lord and Savior Jesus Christ for His guidance and supply of wisdom, knowledge and understanding which aided us in successfully carrying out this project.

ACKNOWLEDGEMENT

Our profound gratitude goes to our Lord and Savior, Jesus Christ, for giving us the grace to be able to successfully complete this project.

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ABBREVIATION AND KEYWORDS

A.C- Alternating Current

CO_2- Carbon Dioxide

D.C- Direct Current

H.E.S- Heat Storage Medium

H.T.F- Heat Transfer Fluid

P.C.M- Phase Change Material

P.I.D- Proportional Integral Derivative

S.H.S- Sensible Heat Storage

T.E.S- Thermal Energy Storage

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ABSTRACT

This project presents the design and fabrication of a system capable of reheating food and maintaining its temperature. Heat was generated by converting the electrical energy derived from both the Alternating Current (A.C) and Direct Current (D.C) source.

The A.C circuit consisted of a heating element of **220V, 1kW** power rating, and an electrical outlet a thermocouple and a temperature controller; the D.C circuit consisted of a mobile filament of **6V, 55W** power rating, a dry cell D.C lead battery of **12V and 18Ah** a thermocouple and temperature controller. A cup of water, meat pie, and a bowl of cooked rice was used to test the system's performance and the set temperature was **60 degrees (ºC).**

At the end of the A.C experiment, it took the system approximately **7 minutes** to reach the set temperature in the case of water, **7 minutes** for the meat pie, and **6 minutes** for the cooked rice**.** Due to heat transfer conditions, the food overheated; the water reached a maximum temperature of **83 degrees** and the meat pie reached a maximum temperature of **81 degrees (ºC)**. The time taken for the food to reach the set temperature value after heating was approximately **45 minutes.**

At the end of the D.C experiment, it took the system approximately **22 minutes** to reach the set temperature in the case of water, **20 minutes** for the meat pie, and **21 minutes** for the cooked rice**.** Due to heat transfer conditions, the temperature of the food increased further; the water reached a maximum temperature of **70 degrees,** the meat pie reached a maximum temperature of **66 degrees (ºC)**, and the cooked rice reached a temperature of **68 degrees**. The time taken for the food to reach the set temperature value after heating was approximately **23 minutes.**

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND INFORMATION

Generally, food is said to be safe when it falls outside the temperature range of 5 and 60 °C as pathogen growth is inhibited when the environment is either on the higher temperature end or lower temperature end (Sengar et al., 2022). However, local eateries and people who take food to work for a 9-5 are at risk of having the food get stale even before it is consumed.

A system capable of reheating food is a device that is capable of keeping food warm and heating it to an elevated temperature. It is a system that has been widely done previously but little attention has been placed to its portability and optimization for food (Jad, 2016).

Charcoal has often been used as the fuel for appliances that are capable of heating food. The heat energy from burning charcoal is utilized to heat water in another compartment to create steam, which is then used to heat the compartment containing the food to be warmed. Since carbon is a key component of charcoal, this approach is connected to the production of carbon monoxide as a result of incomplete combustion (Sajid et al., 1993). Anywhere fuel is burnt there is bound to be an emission of carbon monoxide.

Electric energy, which is provided by a heater coupled to an electric circuit, is another energy source that has been used in this industry. Here, the heater may either be connected to a thermostat, which regulates temperatures automatically, or it can be controlled manually by a switch, which requires constant on/off switching (Lancaster, 1914).

Also, according to the World Health Organization, 3 billion people worldwide cook with biomass and coal, which results in 4 million deaths annually from inhaling the accompanying pollutants. In addition to the risks associated with indoor air pollution, using open flames while cooking causes deforestation and soot and CO2 emissions that contribute to climate change. The adoption of fuel-efficient stoves can lessen the negative consequences of present cooking techniques, but not completely remove them. Solar cookers reduce health and environmental risks, although they are not always widely used for a variety of reasons, such as inconvenience, dissimilarity from conventional cooking techniques, and power shortages. Cooking with natural gas reduces the health risks associated with indoor air pollution, but it is still an expensive choice (Watkins et al, 2017).

A system capable of reheating food will keep food warm and infection free, by maintaining the food at elevated temperatures.

There have been researches done that lean toward this topic. For instance, research was done on the possibility of reheating the food stored in a food delivery container by using the exhaust gas supplied by the exhaust pipe of a motorcycle (Akshay et al, 2019). There has also been research on the possibility of using a Phase Change Material (P.C.M) as a heat storage unit in a solar-powered cooking system (Usha et al, 2023). Research was also performed on how possible it would be to recover the heat usually released from a car engine and supply it to an onboard food warmer (Pandiyaranjan et al, 2012; Mathivanan et al, 2017). A project was done on the potential of supplying electricity to a portable food display warmer used by food vendors in Kenya by means of solar energy (Khasoa and Gatu, 2020). There has been some research on the potential of using Ohmic Heating Equipment to heat food in the processing of food (Sinthiya, 2015). Research has also been done on how suitable novel solar cookers would be for small families (Namrata et al, 2013). A case study has also been done on the comparison of two hot box solar cookers that differ in geometry but are similar aperture area (Namrata, 2015).

1.2. PROBLEM STATEMENT

Food warmers, thermos flasks and cooking pots and pans all have the same problem:

1. Insufficient insulation thickness to reduce the loss of heat
2. Poor materials Selection for regulation of the rate of heat transfer
3. Reduction of the food's flavour and texture as a result of the rapid temperature loss.

1.3. AIMS AND OBJECTIVE

This project aims to design and fabricate a prototype system capable of reheating food and maintaining its temperature by using Alternating Current and Direct Current as thermal energy source.

The objectives are:

1. To review the relevant literature related to the design and fabrication of a system capable of reheating food and maintaining its temperature.
2. To design and fabricate a system capable of reheating food and maintaining its temperature.
3. To control the temperature generated to reheat the food.
4. To maintain the temperature generated for a long period of time by installing insulation materials of suitable thickness.

1.4. SIGNIFICANCE OF THE STUDY

Cooked food storage is of utmost importance for several reasons. In relation to this project, here are some key reasons highlighting the importance of food storage:

1. Food Preservation: Proper storage of cooked food aids in the maintenance of its safety through restricting the growth of harmful bacteria, such as: Salmonella and E. coli.
2. Preservation of Nutrients: Exposure of cooked food to air, light, and high temperatures results in the loss of some of its nutrients over time. Proper storage aids

in preserving the nutritional value of cooked food, hence it makes sure that the necessary vitamins and minerals, as well as other useful compounds remain intact.

3. Quality Maintenance: Cooked food storage plays a key role in the maintenance of the food's texture, flavor and overall quality. Improper storage tends to result in the loss of flavor, texture deterioration, and development of off-flavors or odors.
4. Minimizing Food Waste: Proper storage of cooked food prevents it from spoiling prematurely, in other words it extends its shelf life.

To ensure effective food storage, it is important to follow guidelines for temperature control. Maintaining the proper temperature of cooked food is crucial for several reasons, primarily related to food safety and quality. The key points highlighting importance of maintaining the temperature of cooked food are listed as follows:

1. Food Safety: Bacteria multiply quickly within, what is known as, the "danger zone" temperature range of 4 degrees Celsius to 60 degrees Celsius (that is, 4C to 60C or 40F to 140F). Therefore, as earlier stated, proper temperature regulation prevents the growth of harmful bacteria as well as other micro-organisms that can cause food-borne diseases (Kendall and Dimond, 2012).
2. Pathogen Inactivation: Cooking food at the apt temperature helps to eliminate pathogens and parasites that may be present in the undercooked ingredients (Rebecca and Julie, 2022).
3. Food Quality: Just as proper storage of cooked food maintains its quality, maintaining the proper temperature also preserves the quality and flavor of cooked food (Kendall and Dimond, 2012).

To maintain cooked food temperature effectively, it is often advised to use the necessary food storage equipment. The food flask is one of such storage equipment.

The food flask, also referred to as a thermos or insulated food container, is a portable container designed to preserve the temperature of food for an extended period of time. However, it has the following limitations:

1. Transfer of heat energy from the inner wall of the flask to the outer wall by conduction as well as exchange of heat between the outer surface of the flask and the environment of the flask result to a gradual decrease in temperature of the food (Yunus and Afshin, 2002).
2. Insufficient layering of the outer and inner walls with insulation and conduction materials respectively, insufficient inner/outer wall thickness, and/or poor selection of insulation and conduction materials contribute to the loss of thermal energy in the flask (Yunus and Afshin, 2002).
3. Poorly designed flask seal and cover used to reduce the exchange of heat between the inner layer and the surrounding (Yunus and Afshin, 2002).
4. Formation of water droplets as a result of the condensation of steam emitted from the food due to the temperature decrease within the flask which in turn decreases the quality of the food (Yunus and Afshin, 2002).

To tackle these problems, the portable food warmer was invented to heat and keep food at a desired temperature anywhere and anytime. This is possible as a result of the use of an electric heating element which can be powered either by a battery or an electric outlet.

1.5. SCOPE OF WORK

The scope of this work entails the discussion of concepts related to this project, a brief history of these concepts, their components and working principles, required criteria for determination of thermal storage and heat transfer and review of literatures related to this project, the design and fabrication of a system capable of reheating food and maintaining its temperature using both D.C and A.C, conducting experiments on the fabricated system, and obtaining a conclusion and recommendation.

1.6. METHODOLOGY

The approach of this study includes;

1. Designing a geometric model of the food heating system using SolidWorks.
2. Fabricate the designed model using locally materials
3. To perform evaluation from the physical model

CHAPTER 2

LITERATURE REVIEW

2.1. OVERVIEW

Reheating food is a common practice in both domestic and commercial settings (Anthony, 2020). The design and fabrication of efficient reheating systems have garnered attention due to the importance of preserving food quality, safety and energy efficiency (Anil, 2019).

Several forms of reheating food exist. For instance, the conventional cooking stove that makes use of biomass (e.g. Charcoal, Firewood, etc.) and fossil fuels (e.g. Dual Purpose Kerosene (D.P.K), Methane gas, etc.), the solar cooker which makes use of Phase Change Materials (P.C.Ms), Solar Collectors or Photovoltaic Cells, the Microwave oven which makes use of emitted microwaves to reheat food, and the Electric Cookers which heat up food using electricity (Sajid et al, 1993; Watkins et al, 2017).

Nowadays, sustainability is one of the most considered key factors in engineering. Therefore, efforts are being made to eliminate the use of biomass and fossil fuels as sources of energy generation by designing and manufacturing machines and systems capable of doing so (Katlego et al, 2021).

The solar cooker is one of such systems. It draws energy directly from the sun and converts it to thermal energy which in turn is used to heat and reheat food (Aligarh University, 2023). However, due to various limitations such as: its inability to be operated in the absence of sunlight, the inconsistency in the weather (e.g. if that day is rainy or cloudy), and the long period of time taken for the food to get done. It is not considered the best method of heating and cooking food. Improvements such as the Thermal Energy Storage (T.E.S) cooker and the Solar Photovoltaic cooker is also considered as alternatives (Hamk University, 2018).

This literature review aims to provide insight on these three specific forms of cooking earlier discussed, the modes of heat transfer, the required criteria for heat storage, the constraints of heat storage devices, and review related literature with the goal of using these points to highlight the components, working principle and performance of our system.

2.2. THE SOLAR FOOD HEATERS

Solar food heaters, in the context of this literature, is a term used to describe machines and systems that cook and reheat food using solar energy, i.e. the energy derived from the sun. While for some it is a direct conversion from solar energy to thermal energy, for others it is an indirect conversion (Aligarh University, 2023; St. Anne's College, 2013; C.C.S University, 2023).

2.2.1. CLASSIFICATION OF SOLAR FOOD HEATERS

In this Literature, the solar food heaters are classified based on the mode of solar energy conversion. They include:

1. Solar Cookers
2. Solar Thermal Energy Storage (T.E.S) Cookers
3. Solar Photovoltaic (P.V) Cookers

2.2.1.1. Solar Cookers

According to Wikipedia, a solar cooker is a device which uses solar energy to heat, cook or pasteurize liquid and solid food materials (Aligarh University, 2023). It is a device used for cooking food with the light energy derived directly from the sun, usually employing reflective panels (i.e. Concave mirrors) to focus the light on a dark-colored pot in an insulated box. The pot gets heated by converting solar energy into thermal energy (Hamk University, 2018).

There are three types of solar cookers:

1. Solar Box Cookers
2. Solar Panel Cookers
3. Solar Parabolic Cookers

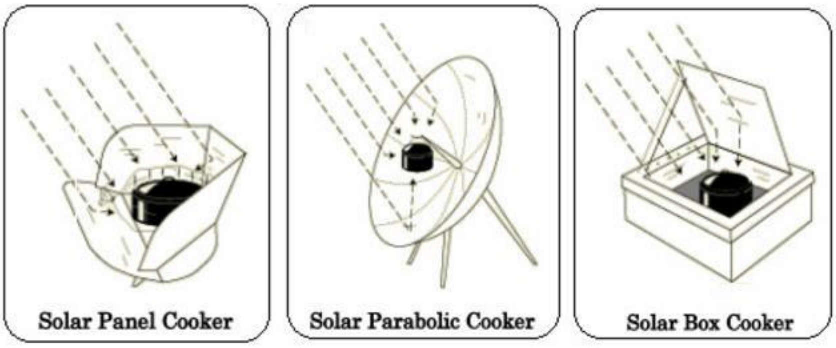

Fig. 2.1: The types of Solar Cookers

Source: https://lifeexperience.wordpress.com/2016/01/21/solar-cookers/

1. **Solar Box:**

   The Solar Box performs cooking of food by absorbing the rays of the sun (Hamk University, 2018). This cooker can either have a transparent top plastic or a glass covering, which can be opened to allow pots with food to be placed inside. The sunlight reaches the panels and reflects into the box, where the heat is trapped. With the help of several mirrors, foil or metal reflectors, extra sun light is directed into it. Cooking containers and the inside bottom of the cooker are dark-colored or black. Its interior walls are insulated and can be reflective for additional reduction of heat loss by radiation and increase of light concentration on the cooking pot (Aligarh University, 2023). Solar ovens can reach temperatures comparable to those of traditional gas and electric ovens, i.e. about 200 degrees C (Hamk University, 2018). A dark colored cookware is preferably used since it is capable of absorbing and retaining the heat better.

2. **Solar Panel:**

   Solar panel cookers are the simplest and quite budget-friendly type of solar cookers. It possesses small reflective flat or curved surfaces, which are used to reflect light and then concentrate it onto a cookware; these solar cookers typically generate energy sufficient to cook on low temperatures (Hamk University, 2018). A heat resistant pot can then be put inside the cooker. The pot is usually covered with a transparent material (e.g. glass) to avoid losing heat and blocking sunrays (Aligarh University, 2023). Panel cookers are most effective at windless or wind protected areas, and can generate temperatures up to 150 degrees °C (Hamk University, 2018).

3. **Solar Parabolic Cooker:**

   Parabolic cookers are a type of solar cookers usually made from curved reflective sheets or small mirrors, which focus solar radiation on a small area, where the cooking pot is positioned. They produce a high temperature on the focus point, and are therefore very effective. However, they are more expensive than simple panel cookers (Aligarh University, 2023).While concentrating sunlight to the pot, parabolic solar cookers can generate temperatures over 200 degrees °C. These can be operated from just after sunrise until sunset, even in sub-zero temperatures, as long as they have direct access to the sun. The efficiency of the parabolic cooker is determined by the quality, size and curvature of the reflector (Hamk University, 2018).

2.2.1.2. Solar Thermal Energy Storage Cookers

Although the Solar Cooker is a useful machine, it also has its limitations. These limitations include: the availability of the sun (i.e., its inability to be used in the evening times and at night, cloudy and rainy days), and the amount of time it takes to prepare the food; therefore, Thermal Energy Storage can be installed to the Solar Cooker to be able to cover up for the Solar Cooker's limitations (St. Anne's College, 2013). Thermal Energy Storage (T.E.S) is a form of technology that keeps and preserves thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation (Ioan, 2017).

There are three types of T.E.S:

1. Sensible Heat Storage
2. Latent Heat Storage
3. Chemical Storage

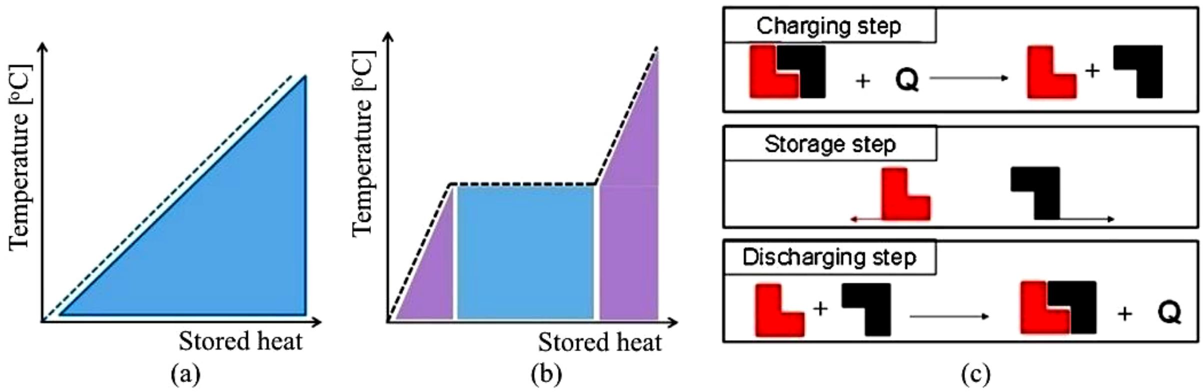

Fig 2.2: (a) Sensible Heat Storage (b) Latent Heat Storage (c) Chemical Storage

Source: In: Advances in Energy Research, Volume 27

1. **Sensible Heat Storage:**

   Sensible Heat Storage (S.H.S) is the simplest method based on the fact that storing thermal energy is done by heating or cooling a liquid or solid storage medium, e.g. water, sand, molten salts or rocks (Ioan, 2017). Water is considered to be the best S.H.S liquid available since it is cheap and possesses high specific heat. However, it is usually advised that antifreeze should be added to the water to ensure that the fluid temperature drops below 0 degrees ℃ (Charles, 1979).

2. **Latent Heat Storage:**

Latent Heat Storage (L.H.S) is another type of Thermal Energy Storage that stores the heat mainly in the phase-change process (i.e. Phase Change Materials (P.C.M) are used) at a reasonably constant temperature; and it is directly connected to the substance's latent heat (Ioan, 2017). For L.H.S, the energy storage density is inversely proportional to the volume; in other words, as the energy storage density increases, the volume decreases (Ioan, 2017). Phase Change Materials (P.C.Ms) are substances which liberate and absorb sufficient energy at phase transition to provide useful heat or cooling (Ioan, 2017). There are three types of P.C.Ms:

a. Solid-Liquid

b. Liquid-Gas

c. Solid-Solid

However, since high volumetric energy storage density is a necessity, only Solid-Liquid or Solid-Solid transformation with significant enthalpy changes are of practical interest (Charles, 1979)

3. **Chemical Storage:**

For Chemical Storage, thermal energy is stored as the bond energy of a chemical compound and is then released; this process is then repeated, i.e. it is a reversible reaction (Charles, 1979). The advantages of this type of T.E.S are that setting up this method cheap and that significant energy storage densities are possible, even at ambient conditions. However, to reduce sensible heat losses and provide efficient energy storage, careful heat exchange between products and reactants is necessary for some applications (Charles, 1979). Chemical Storage of thermal energy is done using three methods:

a. Thermochemical storage

b. Heat Pump Storage

c. Chemical Heat Pipe

Thermochemical storage (T.C.S) makes use of Thermochemical Materials (T.C.M) which is capable of storing and releasing heat by a reversible endothermic/exothermic reaction process (Ioan, 2017). The general reaction taking place is of the form: $\boldsymbol{A} \rightleftharpoons \boldsymbol{B}+\boldsymbol{C}$. During the charging process, heat is applied on the material A which splits it into two parts B and C. The parts B and C are then stored until the discharge process is required, where the two parts combine once again at a certain pressure and temperature and the energy obtained is released (Ioan, 2017).

Heat Pump Storage provides high storage capacity and high heat of reaction compared to sensible heat generated by absorption (Wongsuwan et al, 2001). Low temperature sources attached to a suitable heat pump increases the heat to a higher temperature; this is made possible either by consumption of electricity, i.e. Vapor Compression Heat Pumps, or by means of thermal energy, i.e. Vapor Absorption and Solid-Gas sorption Heat Pumps (Wongsuwan et al, 2001). The general reaction is of the form $\boldsymbol{B}+\boldsymbol{C} \rightleftharpoons \boldsymbol{A}$, where the forward and backward reactions occur at two different temperatures, thus allowing the increase of thermal energy from low to higher temperature (Wongsuwan et al, 2001).

Chemical Heat Pipe is another form of Chemical storage where the thermal energy absorbing reaction occurs at the source, and the reverse heat emitting reaction occurs at the point of consumption, with a pipe system combined (Wettermark, 1980). Here, thermal energy is stored and transported using an endothermic reaction (Aldo, 2001).

2.2.1.3. Solar Photovoltaic Cookers

This type Solar Heater has the advantage of being used to cook food both indoors and outdoors; this is made possible as a result of the use of Photovoltaic cells.

A solar cell, or photovoltaic (P.V) cell, is an electrical device that converts the energy of light (specifically solar energy) directly into electricity through the "Photovoltaic effect"; which is a physical and chemical phenomenon (C.C.S University, 2023). The Photovoltaic effect is the process where light, which is pure energy, enters a P.V cell and imparts enough energy to some electrons (negatively charged particles) to excite and liberate them. An installed potential barrier within the cell acts upon these free electrons to produce a voltage which can be used to drive a current through a circuit (SERI, 1982).

Based on the types of crystal used, solar cells are classified into three:

1. Mono-crystalline Silicon cells
2. Poly-crystalline Silicon cells
3. Amorphous Silicon cells

1. **Mono-crystalline Silicon cell:**

   Mono-crystalline Silicon cell is a type of P.V cell produced for a single crystal silicon structure which is uniform in shape as a result of the entire structure being composed of pure silicon. Since it is pure and defect-free, it possesses a very high efficiency (about 15 to 20%) (C.C.S University, 2023; St. Anne's College, 2013). Hence, these types of P.V cells are also widely used in photovoltaic panel construction (St. Anne's College, 2013).

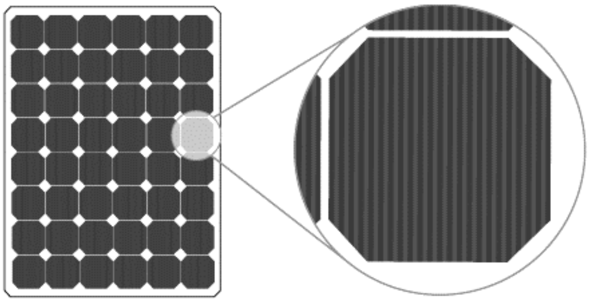

Fig 2.3: Mono-crystalline Silicon cell

Source: St. Anne's College, 2013

2. **Polycrystalline silicon cell:**

   Polycrystalline silicon cell is a type of P.V cell produced by the solidification of liquid silicon. This process results in the formation of grains of crystals within the silicon molecular structure (C.C.S University, 2023). These grains reduce the efficiency of these cells (about 10 to 14%) by restricting the flow of electrons through it; this is done by causing the negative electrons to bond with the positive holes, hence reducing the power output of the cell (St. Anne's College, 2013).

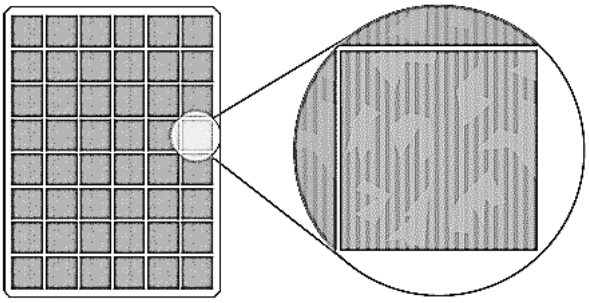

Fig. 2.4: Poly-crystalline Silicon cell

Source: St. Anne's College, 2013

3. **Amorphous silicon cell:**

   Amorphous silicon or Thin Film cell is another type of P.V cell produced by depositing a thin semiconductor layer of P.V materials onto a glass, metal or plastic foil plate through the process of printing or spraying (C.C.S University, 2023; St. Anne's College, 2013). However, even though it is lightweight, flexible and have a higher light absorption compared to the mono-crystalline and poly-crystalline silicon cell, it possesses the lowest efficiency (about 5 to 7%); this is due to its non-single crystal structure, thus larger sized cells are required (C.C.S University, 2023; St. Anne's College, 2013).

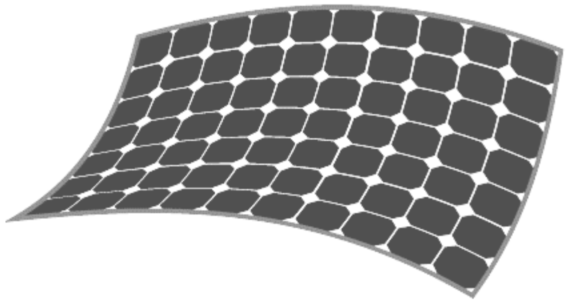

Fig. 2.5: Amorphous Silicon cell

Source: St. Anne's College, 2013

2.2.2. HISTORY OF SOLAR HEATERS

Man's quest to harness the sun goes far back to the 7th Century B.C where the ancient Romans and Greeks used magnifying glasses and mirrors to light fires by focusing the sun's rays to the desired spot (USDE, 2001). History also that the ancient Chinese, Egyptians and Greeks successfully captured the thermal energy emitted by the sun during the day using solar mass, the trapped heat was then released to keep their homes warm; it was also used to evaporate water which had a cooling effect on their house (Lauren , 2022). The ancient Romans are also famous for their bathhouses which trapped the sun's energy to heat their water; this was possible using a hypocaust, i.e., a process where hot air is circulated beneath the floors which are raised. The walls were made hollow to allow for the generation of steam as a result of the confluence of hot air and water from the south-facing baths (Lauren, 2022). These bathhouses were used from the 1st to the 4th Century A.D (USDE, 2001).

German Physicist Tschirnhausen used solar energy to boil water placed in a clay pot by focusing the sun's rays using a large lens (Jad, 2016). This was recorded in the first published report on solar cookers by French-Swiss scientist Horace de Saussure in 1767. Horace performed his experiment with the aim of cooking food using solar energy (Beth and Dan, 1992), his experiment is considered by many to be the first attempt made to cook food using solar energy. He designed an insulated box which resembled a greenhouse, it had an opening and three to five layers of glass (Lauren, 2022). His solar cooker was used by Sir John Herschel to cook his meals during his expedition in South Africa in the 1830's. (USDE, 2001). His invention became the foundation of the solar collectors later invented and developed in the 1800's and 1900's that were capable of heating houses, supplying hot water, cooking food and generating electricity (Lauren, 2022).

Currently, studies and experiments are being conducted on the possibility of storing the heat derived from the sun by the collectors using thermal energy storage (Aligarh University, 2023) and photovoltaic cells (St. Anne's College, 2013).

2.2.3. COMPONENTS OF SOLAR HEATERS

2.2.3.1. Solar Cookers

Irrespective of type, the solar cooker has these basic components:

1. Cooking Containers; and
2. Plane Mirror Reflector

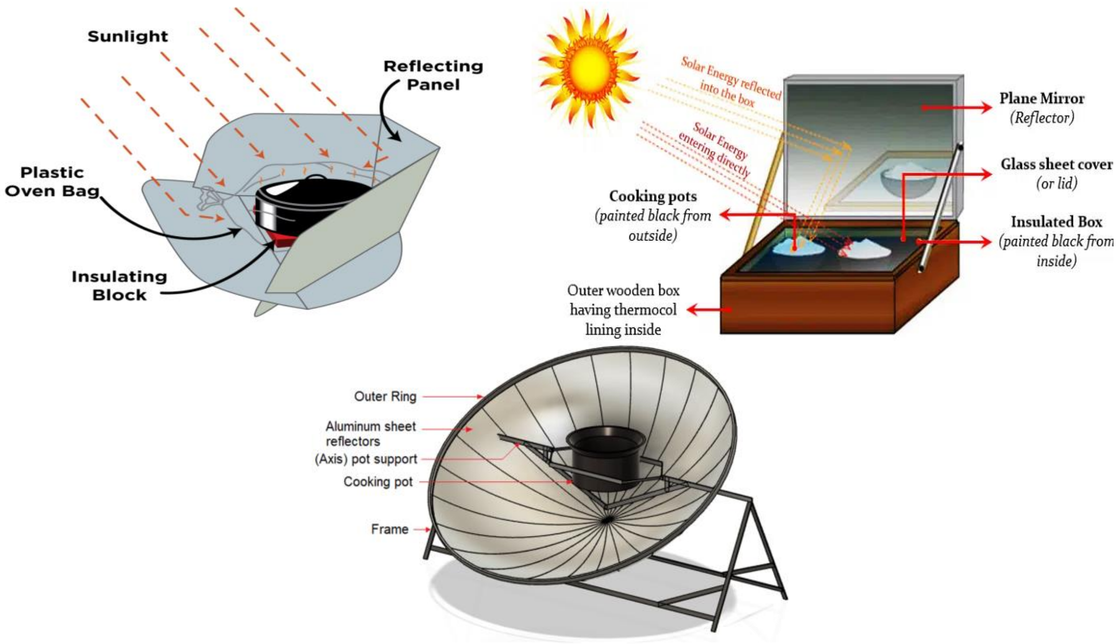

Fig. 2.6: Components of the Solar Panel (top left corner), the Solar Box (top right corner), and the Parabolic Cooker (bottom center)

Source:

https://images.collegdunia.com/public/image/67bd6692b7348e50499a33b32a40a9be.webp, https://pub.mdpi-res.com/energies/energies-15-08775/article_deploy/html/images/energies-15-08775-g004.png?1669198563, energyresearch.ucf.edu/wp-content/uploads/2021/07/panel-cooker-1024x834.png

2.2.3.2. Thermal Energy Storage System

The T.E.S system consists of the following components:

1. The Heat Storage Material

2. The heat-exchange system between the Heat Storage Medium (HSM) and the Heat Transfer Fluid (HTF)

3. The containment and thermal insulation system.

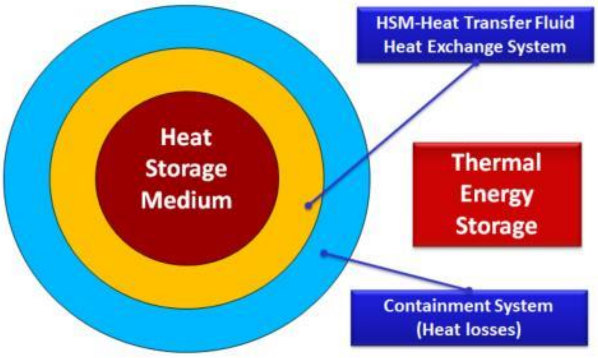

Fig. 2.7: The components of the Thermal Heat Storage System

Source: E.N.E.A research and innovation on Thermal Energy Storage for C.S.P plants

2.2.3.3. Solar Photovoltaic System

A typical solar P.V system consists of the following components:

1. Solar or Photovoltaic Module
2. Solar Charge Controller
3. Battery
4. Inverter
5. Lightning protection

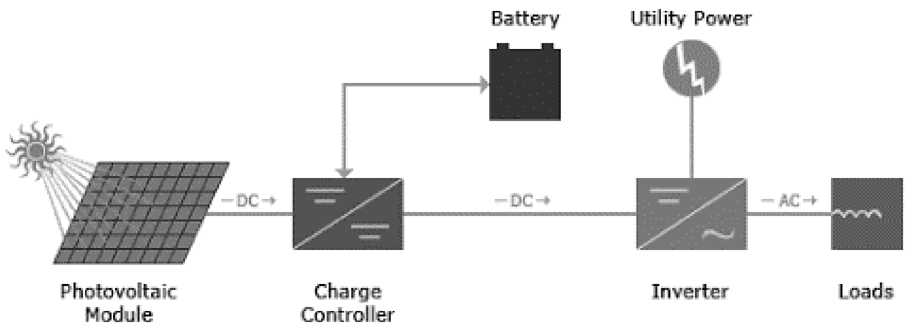

Fig. 2.8: The components of the Solar Photovoltaic System

Source: St. Anne's College, 2013

2.2.4. WORKING PRINCIPLE OF SOLAR HEATERS

2.2.4.1. Solar Cookers

The solar cooker operates in this manner:

1. **Sunlight Concentration:** A mirrored surface with high specular reflection is used to concentrate light from the Sun into a small cooking area. Depending on the surface geometry, sunlight could be concentrated by several orders of magnitude producing temperatures high enough to melt salt and metal. Such high temperatures are unnecessary for most household solar cooking applications. Solar cooking products are typically designed to achieve temperatures of 65 °C (baking temperatures) to 400 °C (grilling/searing temperatures) on a sunny day (Aligarh University, 2023).
2. **Solar to Thermal Energy Conversion:** Solar cookers concentrate sunlight onto a receiver such as a cooking pan or pot. The interaction between the light energy and the receiver material converts light to heat and this is called absorption. The conversion is maximized by using materials that absorb, conduct, and retain heat. Pots and pans used on solar cookers should be matte black in color to maximize absorption (Aligarh University, 2023).

3. **Thermal Energy Retention:** It is important to reduce convection by isolating the air inside the cooker from the air outside the cooker. Simply using a glass lid on your pot enhances light absorption from the top of the pan and provides a greenhouse effect that improves heat retention and minimizes convection loss. This "glazing" transmits incoming visible sunlight but is opaque to escaping infrared thermal radiation. In resource constrained settings, a high-temperature plastic bag can serve a similar function, trapping air inside and making it possible to reach temperatures on cold and windy days similar to those possible on hot days (Aligarh University, 2023).

2.2.4.2. Thermal Energy Storage System

A T.E.S system consists of three types: Sensible heat storage, Latent heat storage, and thermochemical storage systems. Each of these types has their respective working principles as discussed below:

1. **Sensible Heat Storage:**

   In sensible heat storage (SHS), thermal energy is stored by elevating the temperature of a solid or liquid. SHS system operate during the charge and discharge process using the heat capacity and the change in temperature of the material; the amount of heat stored is dependent upon the specific heat of the medium, the temperature change, and the amount of storage material (Yogesh and Jibhakate, 2013).

2. **Latent Heat Storage:**

   Latent heat storage is the process of heating a material until it experiences a phase change, from solid to liquid or liquid to gas. When the material reaches its phase change temperature it absorbs a large amount of thermal energy, at constant temperature, in order to carry out the transformation. The heat absorbed during the process is known as latent heat of fusion or vaporization depending on the case. The energy stored during the phase change is released when the material is cooled down again (Dusan et al, 2010).

3. **Thermochemical Storage:**

   Thermochemical energy storage is based on chemical reactions with high energy involved in the process. The products of the reaction are stored separately, and the stored heat is retrieved when the reverse reaction occurs. Therefore, only reversible reactions can be used for thermochemical storage processes (Andrea et al, 2022).

2.2.4.3. Solar Photovoltaic System

The solar P.V cell operates as follows:

1. **Light Absorption:** Photons in the sun beams strike the solar cell and are absorbed by semiconducting materials, e.g., doped silicon (C.C.S University, 2023).
2. **Electron Excitement:** Energy from the photon is then transferred to an electron of the semiconducting material, exciting it and causing it to move to a higher energy level known as the conduction band. In their excited state in the conduction band, these electrons are free to move through the material, and it is this motion of the electron that creates an electric current in the cell (St. Anne's College, 2013).
3. **Electric Current:** An array of solar cells converts the solar energy into useful electrical energy in the form of Direct Current (D.C). An inverter can be installed to convert it to Alternating Current (A.C).

2.3. THE MICROWAVE OVEN

The Microwave Oven is an electrical kitchen appliance used to reheat cooked food whose temperature is low; it is able to do this using "microwaves" (Gupta and Wong, 2007).

Microwaves are a form of electromagnetic radiation that is very similar to sunlight and radio waves but at different frequencies; it refers to A.C signals with frequencies between 300 MHz (i.e., $f = 3 \times 10^8$ Hz) to 300 GHz (i.e., $f = 3 \times 10^{11}$ Hz) (Hua, 2017).

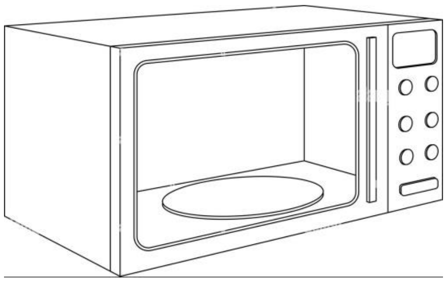

Fig 2.9: The Microwave Oven

Source: www.alamy.com

2.3.1. HISTORY OF THE MICROWAVE OVEN

Before the oven was invented, microwaves were discovered. The road to its discovery began in 1819 when Hans Christian Oersted during his experiment on a wire and a compass discovered that as current flowed through the wire, he compass needle moved (Hua, 2017). Later in1831, a chemist Michael Faraday discovered electromagnetic induction (Gupta and Wong, 2007; Hua, 2017). Renowned physicist James Clerk Maxwell began working on Faraday's concept on the "lines of force" in his mid-20s, and in 1864, he proposed the theory of electromagnetics. The electromagnetic field theory proposed by Maxwell hypothesized the presence of invisible electromagnetic waves (Hua, 2017). Maxwell's theory was confirmed by German Engineer Heinrich Hertz who proved the existence invisible electromagnetic waves using a wavelength longer than that of light (Hua, 2017).

In the 1890s, the Indian physicist Jagadish Chandra Bose performed further experiments on Maxwell's discovery using an improved apparatus at higher frequencies ranging from 60 to 120 GHz (Hua, 2017). From 1900 to the 1930s, research and experiments on microwaves led to the development of basic radar concepts. However, its development accelerated during World War II with the urgent need to improve radar detection of enemy aircraft and submarines and the invention of the high-power cavity magnetron (Hua, 2017; Gupta and Wong, 2007).

The invention of the microwave oven is credited to three particular men: an inventor, Dr. Percy Spencer, an entrepreneur, Lawrence Marshall, and a Marketer, George Foerstner (Leo, 1989).

During a radar-related research project around 1946, Dr. Percy Spencer, a self-taught engineer with the Raytheon Corporation, discovered something very unusual. While testing a new vacuum tube (a type of magnetron), he discovered that the candy bar in his pocket had melted. This piqued Dr. Spencer's curiosity, so he tried another experiment. This time he placed some popcorn kernels near the tube and, while perhaps standing a little farther away, he watched with an inventive sparkle in his eye as the popcorn sputtered, cracked and popped all over his lab. This accidental discovery motivated Dr. Spencer to design and manufacture an oven that was able to cook food (Hua, 2017).

In 1947, the world's first microwave oven was by Raytheon Corporation which later commercialized it using the name "Radarange". Later models were manufactured each more improved than the previous model. All this was spearheaded by co-founder and president of Raytheon Corporation, Lawrence Marshall (Leo, 1989; Hua, 2017).

In 1964, George Foerstner, owner of a refrigeration company, purchased Amana, a company that specialized in the production of home appliances; after this successful acquisition, he decided to try producing microwave ovens. After discussions with Raytheon Corporation and a few years of design improvements, the first countertop domestic microwave oven was displayed at a press conference in Chicago in 1967; and within that same year, it was commercialized (Leo, 1989).

2.3.2. COMPONENTS OF THE MICROWAVE OVEN

A microwave oven consists of the following components:

1. Turning tables
2. Reflecting wall
3. Common wave guide
4. Magnetrons
5. Electrical Switch

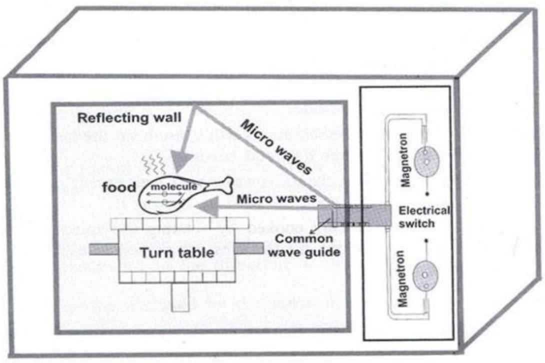

Fig 2.10: Components of a Microwave Oven

Source: Rohini College of Engineering and Technology

2.3.3. WORKING PRINCIPLE OF THE MICROWAVE OVEN

A microwave oven uses microwaves to heat food; these waves penetrate the food and excite water and fat molecules almost evenly throughout the food. There is no heat transfer by conduction, because heating is done by microwaves (Yonsei University, 2004).

2.4. THE ELECTRIC COOKER

As the name implies, an electric cooker is a system that cooks and heats up food. This is done by converting electrical energy to solar energy. The time taken to prepare a meal using an electric cooker depends on the voltage and power rating of the heating element.

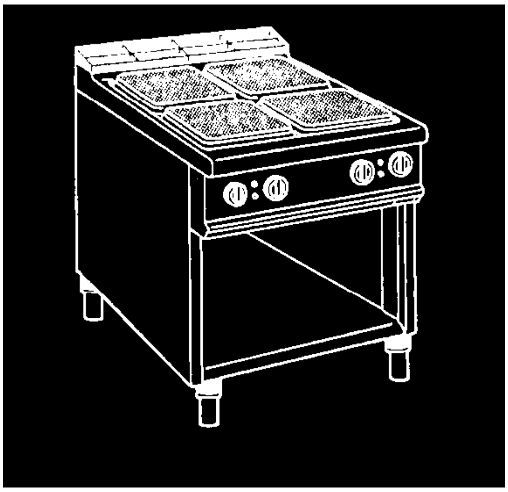

Fig. 2.11: The Electric Cooker

Source: Mastro Catering Equipment

2.4.1. HISTORY OF THE ELECTRIC COOKER

The method of cooking in ancient days was to dig a deep hole in the ground and to tunnel a chamber in the form of an arched oven. Into this, the fuel was placed and burnt until the earth and stones surrounding the chamber were very hot; once it was hot enough, the chamber was then cleared of the remains of the fuel and the Objects to be cooked were placed into it, the opening being sealed with stones and earth. The heat stored in the walls of the chamber was high enough to thoroughly and properly cook all that was required, however, it was usual to leave the food in the oven for many hours due to the comparatively low and uniform temperature; this meant that there was no possibility of the food being burnt, or any likelihood of its being over- cooked (Lancaster, 1914).

Experimentally, the idea that electricity could be applied to cooking operations was demonstrated by Franklin so long ago as 1749 , simple operations were carried out using currents furnished by extremely primitive means; more than a century before the invention of the dynamo for generating electricity on a commercial scale (Lancaster, 1914).

Mr. H. J. Dowsing, M. I. E. E., one of the pioneers of Heating and Cooking and founder of the Dowsing Radiant Heat Company, displayed electric cookers and heaters at his stand during the Crystal Palace Electrical Exhibition of 1891. Although most of the apparatus he used are outdated by today's standards, it succeeded in proving that electricity could be used to cook and even warm food (Lancaster, 1914).

2.4.2. COMPONENTS OF THE ELECTRIC COOKER

A typical electric cooker consists of the following components:

1. Line input terminal board
2. Hotplate commutator
3. Pilot lamp
4. Hotplate or Thermal plate
5. Knob
6. Safety thermostat

2.4.3. WORKING PRINCIPLE OF THE ELECTRIC COOKER

The switch upstream of the appliance is put on, this allows for the supply of current to the hotplate. The knob corresponding to the desired hotplate is put on; the amount of heat supplied is then regulated using the knob. The pilot lamp then lights up as soon as the appliance is on.

2.5. THE REQUIRED CRITERIA FOR HEAT TRANSFER AND STORAGE

The following criteria are to be noted when considering thermal storage and heat transfer:

1. Temperature
2. Area
3. Mass
4. Heat Capacity
5. Specific Heat Capacity
6. Thermal Conductivity

7. Heat Transfer Coefficient
8. Insulation Thickness
9. Heat Flow Rate
10. Thermal Diffusivity
11. Thermal Resistance

2.5.1. TEMPERATURE

Temperature (*T*) is defined as the degree of a body's hotness or coldness. It is measured in degree Celsius (ºC), degree Fahrenheit (ºF) and Kelvin (K).

2.5.2. AREA

The surface area (*A*) on which heat is transferred is also a criterion that must be taken into consideration. The body surface area depends on the surface geometry being considered (i.e., 2-dimensional and 3-dimension). Area is measured in squared meters (m^2).

2.5.3. MASS

Mass *(m)* is defined as the quantity of matter adhering together so as to make one body, or quantity, of considerable size. It is measured in Kilograms (kg).

2.5.4. HEAT CAPACITY

Heat capacity (*C*) is the energy required to raise the temperature of a mass of a substance by one degree. It is measured in Joules per Kilogram (J/K).

2.5.5. SPECIFIC HEAT CAPACITY

Specific heat capacity (*c*) is the energy required to raise the temperature of a unit mass of a substance by one degree in a specified way. It is measured in Joules per Kilogram per Kelvin (J/kg.K).

2.5.6. THERMAL CONDUCTIVITY

Thermal Conductivity (k) is defined as a measure of the ability of a material to conduct heat. It is measured in Watts per meter per Kelvin (W/m.K).

2.5.7. CONVECTION HEAT TRANSFER COEFFICIENT

Convection Heat Transfer Coefficient (h) is an experimentally determined parameter whose value depends on all the variables influencing convection such as the surface geometry, the nature of fluid motion, the properties of the fluid, and the bulk fluid velocity. It is measured in Watts per square meter per Kelvin ($W/m^2.K$).

2.5.8. INSULATION THICKNESS

The higher the insulation thickness (x), the lower the heat flow rate. It is measured in meters (m).

2.5.9. HEAT FLOW RATE

Heat Flow Rate (Q) is defined as the ratio of Heat transfer with time. It is measured in Watts (W).

2.5.10. THERMAL DIFFUSIVITY

Thermal diffusivity (α) represents the speed at which heat diffuses through a medium. It is measured in square meters per second (m^2/s).

2.5.11. THERMAL RESISTANCE

Thermal Resistance (R_{th}) is a term used when likening the rate of heat transfer, under steady conditions and room temperature, to an electrical circuit. It is measured in Kelvin per Watts (K/W).

2.6. REVIEW OF RELATED LITERATURE

(Ashkay et al, 2019) designed and fabricated an insulated delivery box capable of maintaining the temperature of the food stored in it using the rejected heat emitted from the motorcycle on which the box is placed; this was done by reducing its size and cost. The system proved to be capable of maintaining the food's temperature and texture, thus it was capable of leaving the customer satisfied.

(Usha et al, 2023) designed and fabricated a solar cooking system with a Phase Change Material (Erythritol) acting as a heat storage unit. The system was designed to be used twice daily, and to feed a family of four. Using rice and potatoes for the experiment, it took approximately 22 minutes to cook the rice in the afternoon, and approximately 29 minutes to cook the potatoes in the evening.

(Pandiyaraja et al, 2012) designed and fabricated an onboard portable food warmer by using the heat rejected from the engine of a car through the cooling system. At the end of the experiment, the maximum heat transfer observed from the coolant, and the outer and inner wall temperatures of the heater chamber was 85 degrees ºC. This was observed to similar in both the theoretical and practical cases.

(Mathivanan et al, 2017) designed and simulated a food warmer that was capable of being heated using the heat rejected from a car engine, and a solar water heater. Water was used to test the system's performance; the maximum heat transfer temperature from the coolant /warm water was observed as 85ºC/50ºC respectively. The inner and outer wall temperature of heater chamber was observed to be almost similar for both the theoretical and practical cases.

(Khasoa and Gatu, 2019) designed and fabricated a solar-powered portable food warmer. The project was embarked upon with the aim of eliminating the use of charcoal as a fuel source for warming cooked food; photovoltaic cells were used as a means of performing this experiment.

(Mahavar et al, 2012) designed and fabricated novel solar cookers capable of feeling a small family. The experiment was aimed at comparing between two box cookers, both possessing good thermal performance, light weight, low-cost and short payback periods. At the end of the experiment, the values of the first figure of merit (F1), second figure of merit (F2) and standard cooking power suggested by Bureau of Indian Standards and International Standard for box-type solar cookers were observed to be to be 0.116 $^oCm^2/W$, 0.466, 30 W and 0.118 $^oCm^2/W$, 0.488, 50 W for SFSC-1 and SFSC-2, respectively.

(Namrata, 2015) performed a comparative theoretical and experimental study of hot box solar cookers of two distinct geometry (cuboid and trapezoidal) and similar aperture areas. The study involved theoretical estimation of energy absorbed by the systems for global solar radiation and analysis of energy distribution between the walls and base plate of the respective absorber trays of the cookers. At the end, the study showed that the performance of the trapezoidal shaped hot box was equivalent to the cuboid shaped hot box in summers; and slightly better in winters.

CHAPTER 3

MATERIALS AND METHODS

3.1.CONCEPTUAL DESIGN

Food warmers are generally known as devices that are used to elevate the temperature of foods to a desired temperature above the range in which it begins to spoil. There are several types of food warmers that focuses on using solar power however our project focuses on harnessing both solar and direct connection to mains. Our food warmer is one that utilizes alternating current (AC) and direct current (DC) to heat up the food contained in the heating chamber. This system of operation was chosen because of the following reasons;

Temperature Regulation

1. On demand usability
2. Availability and cost of materials
3. Power saving

The ability of our food warmer to regulate temperature is as a result of a temperature controller installed into the food warmer system. We decided to capitalize the use of both AC and DC heating mechanisms so as to make our food warming system have a higher chance of being available at all times as opposed to the conventional microwave that's only available when there is power. This method also saves power and cost of purchasing units because of the installed battery that saves power through the use of solar panels to further heat up the contained food.

The target appearance for this project was a microwave which has a vacuum tube (megatron) that's responsible for heating up the food chamber by means of radiation effect. In our case the heating element was placed closed to our heating chamber and separated by a distance of air gap, by reason of this placement the heat is transferred by radiation.

1. AC Heating

This method of heating involves the use of an electric current being sent through a heating element (in our case tungsten – 500watts). By reason of the resistance in the material and potential difference, there's a build up of heat in the material which is then utilized to heat up our food chamber.

2. DC Heating

In this method of heat transfer, the heat is transferred from the heat source (filament bulb) and focused on the material to be heated (in our case heating chamber). The heat is transferred through electromagnetic radiation.

3.2. WORKING PRINCIPLE

The main purpose of our project is to elevate the temperature of already cooked food and store it within a certain temperature range. In order to achieve this, the following will have to take place:

1. The food to be heated is placed in the heating chamber made of stainless steel and then the circuit is turned on. For the AC connection, the desired temperature at which the user wants the food to be kept at is set through a temperature controller (in our case this temperature is 60℃). So the highest temperature value is set at 65℃ to accommodate losses that may occur during the heat transfer process and also a lower temperature of 55℃ is set to keep the food at elevated temperatures that inhibits the growth of pathogens. Also, for the DC heating, a battery is used to power the circuit and a DC temperature controller is used to set the temperature as stated above. A temperature

sensor that senses the high and low temperatures is attached to the system, this sensor is responsible for shutting off the system when the set maximum temperature value is reached and also turning on the system when the minimum temperature is reached.

2. Overtime, the food in the chamber gains enough heat to keep the food in good and healthy conditions for a longer period of time. Heat loss is reduced to the barest minimum due to the double layer mild steel walls surrounding the food compartment that are 1 inch in distance and filled with fibre grass and wood dust.
3. The AC heating element is held in place by the use of a mesh and the DC bulb was welded to it. There are various methods of heating food and the electric heating is considered far superior due to its cleanliness, ease of control, achievement of uniform heating and pollution free methods amongst others.

The working of the food warmer is majorly hinged on the conventional heat transfer methods which are elaborately explained below.

3.3. CONVECTION

The transfer of heat between two bodies by currents of moving gas or fluid is known as convective heat transfer. In free convection, air or water rises and is replaced by a cooler parcel of air or water as it moves away from the hot body. Forced convection effectively removes heat from the body by forcing air or water across its surface (such as during wind or wind-generated water currents). Because convection maintains a sharp temperature gradient between the body and the surrounding air or water, it is an extremely effective means of transferring heat.

Because all foods contains a certain amount of liquid/fluid therefore convection is bound to occur. Heat is transferred by convection by reason of the movement of the hotter food molecules to the top and the downward movement of the colder molecules. Also there's heat transfer by convection through the air space between the food camber and the heating element. Heat transferred by the process of convection can be expressed by the following equation;

$$Q = hA(\Delta T) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.1)$$

$$\Delta T = (T_{HOT} - T_{COLD}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.2)$$

Where:

Q = Rate of heat transfer

A = Area exposed to heat transfer

h = Convective heat transfer coefficient (W/m^2K), this is the "amount of heat transmitted per unit time for a unit temperature difference between the fluid and unit area of surface"

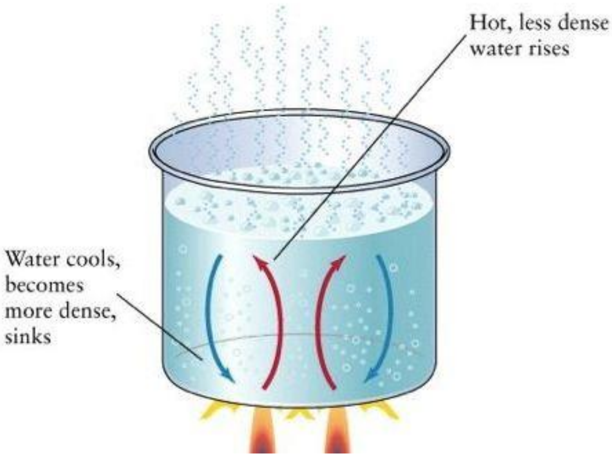

Fig. 3.1: Heat transfer by Convection

Source: 13 Examples of Convection in Everyday Life, studiousguy.com

3.4. CONDUCTION

During thermodynamics study, we looked at how much heat is transferred as a system transition from one equilibrium state to another. However, no time estimate is provided by thermodynamics for the procedure. Meanwhile in heat transfer, we are more interested in the rate of heat transfer while discussing it.

A temperature difference is a necessary condition for heat transmission. Similar to how voltage difference drives electrical current, temperature difference is the driving factor behind heat transmission. You may calculate the overall quantity of heat transfer Q over a period of time by;

$$Q = \int_0^{\Delta t} Q^* \, dt \, (kJ) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.3)$$

Also, the rate of heat transfer per unit area is called heat flux, and the average heat flux on a surface is expressed as

$$q = \frac{Q}{A} \, (W/m^2) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.4)$$

Conduction is the process by which energy is transferred from a substance's more energetic particles to its nearby, less energetic ones as a result of interactions between the particles.

Consider constant conduction through a sizable flat wall with a surface area (A) and a thickness of x = L. ΔT = T2 - T1 represents the temperature differential along the wall.

The general equation for conduction can be obtained from Fourier's Law of Heat Conduction which states that; *the rate of flow of heat through a simple homogeneous solid is directly proportional to the area normal to the direction of heat flow, and to temperature gradient along the path of heat flow.* The mathematical representation of the above statement can be seen below;

$$Q \, \alpha \, A \, . dT/dx \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.5)$$

Removing the constant of proportionality gives

$$Q = -k. AdT/dx \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.6)$$

Where:

Q = Heat flow through a system per unit time (Watts)

A = Surface area of heat flow normal to the direction of flow (m^2)

dT = Temperature difference of the faces of homogeneous solid of thickness 'dx' through which heat flows (℃ or K)

dx = Thickness of the system in the direction of flow (m)

k = Thermal Conductivity

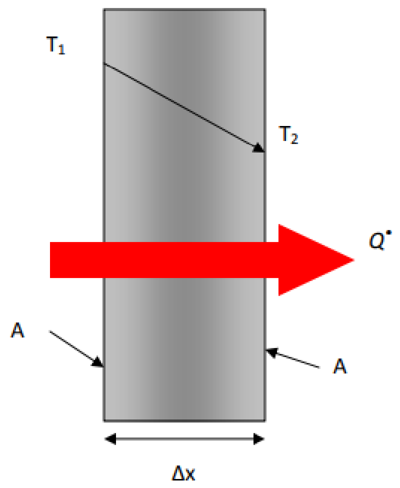

Fig. 3.2: Heat transfer by Conduction

Source: www.fayoum.edu.eg

For our food warmer, heat transfer by conduction plays a major role in transmitting the generated heat to the food placed in the heating chamber. The transfer of heat through the layer of thickness of stainless steel material used then to the food container before it gets to the food itself is through conduction heat transfer method.

3.5. RADIATION

Radiation is a heat transfer process that occurs when heat energy is transferred by electromagnetic phenomenon. Usually in this method of heat transfer there is transfer of heat between surfaces at different temperatures even if there's no medium between them as long as they face each other.

Generally, the radiation energy emitted by a blackbody per unit time and per unit surface area can be determined from the Stefan-Boltzmann Law:

$$E_b = \sigma T^4 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.7)$$

However in many practical problems these three mechanisms combine to generate the total energy flow as in our food warmer system.

3.6. PROPOSED CONCEPTS

For this project, two design concepts were modelled and of which one concept was selected using the decision matrix method.

3.6.1. CONCEPT 1: PORTABLE SOLAR POWERED FOOD WARMING SYSTEM

This concept uses solar power to power a light bulb that eventually does the heating of the food through radiation effect. The design of this concept was such that it required light and inexpensive materials to produce. Also the risk of using a DC bulb to keep food warm was relatively low.

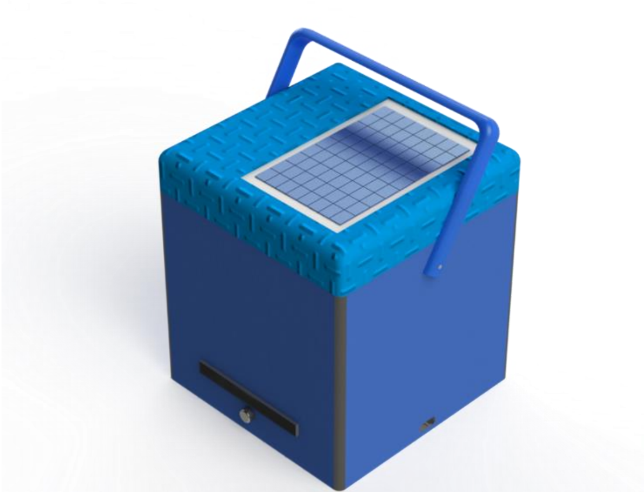

Fig 3.3: The rendered image of Concept 1

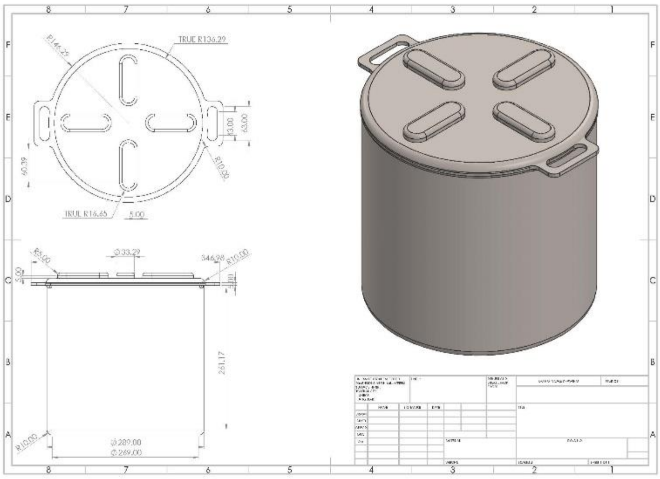

Fig. 3.4: The orthographic and isometric view of the internal compartment of concept 1

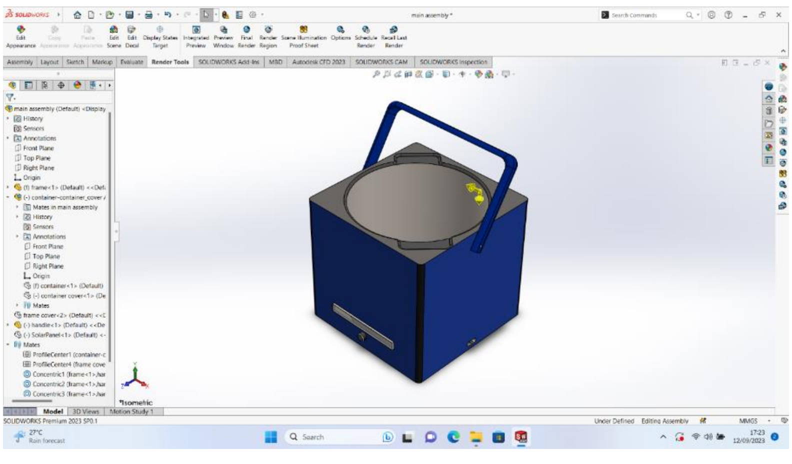

Fig. 3.5: The isometric view of the internal section of concept 1

3.6.2. CONCEPT 2: AC & DC POWERED FOOD WARMER SYSTEM

This particular concept integrates an AC and DC temperature regulator to maintain the set temperature for the food. When the AC controller is in operation, current is sent through a heating element located below the heating chamber and then the food is heated.

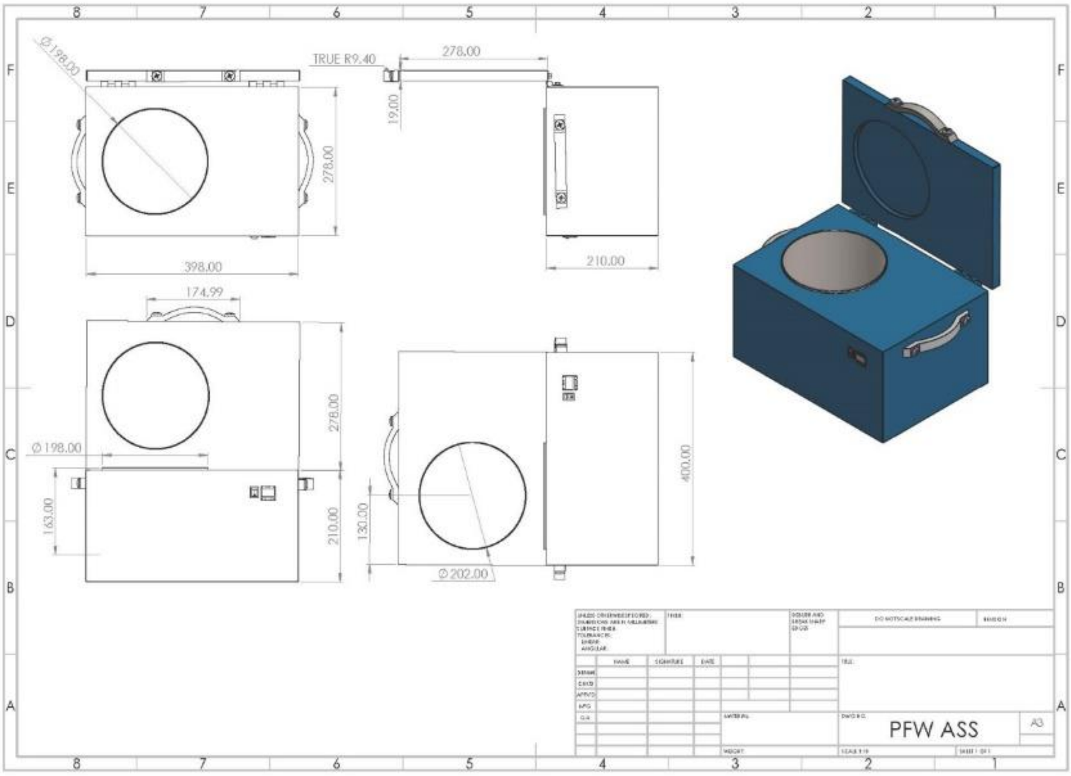

Fig. 3.6: The orthographic and isometric view of concept 2

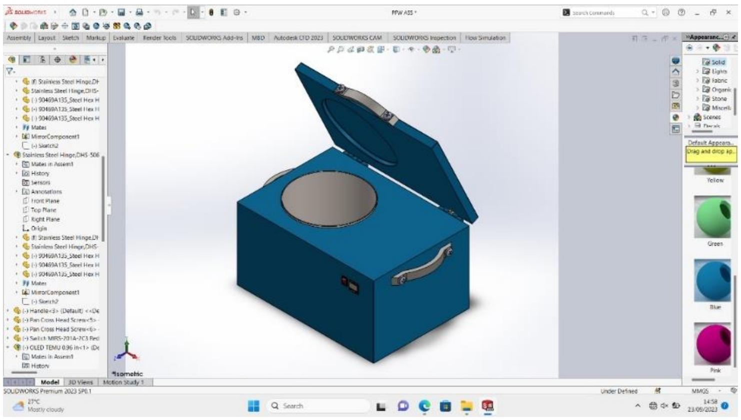

Fig. 3.7: The isometric view of concept 2

3.7. DECISION MATRIX

Only one of the two (2) ideas that have been suggested can be used in the actual fabrication of the food warming system. Consequently, a decision matrix was used to guide our decision-making. The five main factors we thought were most crucial for the design we ultimately chose served as the foundation for our decision matrix. The standards are:

1. Cost
2. Efficiency
3. Practicality
4. Flexibility
5. Aesthetics

Using the different standards above from a scale/weight of 1-5 attached to each, we were able to get an appropriate design solution for our project.

4. **Cost**

   Being that this is an undergraduate project, cost was a very essential thing to consider when choosing or making design decisions so we assigned a weight of 5 to cost. Haven stated the above, concept 1 was the most cost effective because it utilises plastic materials and makes use of less area and only one temperature controller so it was assigned 5. While concept 2 makes the most expensive cause it involves the use of mild steel, stainless steel, heating element and AC temperature controller added to the materials mentioned in concept 1 so for this it was assigned a rating of 3.

5. **Efficiency**

   In terms of the time it takes to achieve the desired temperature and how long the system can retain this heat, concept 2 was assigned a rating of 5 because it comes with an AC heater (using 500W heating element) that rapidly gets to the desired/set temperature value as opposed to when using just the DC heater (Incandescent light bulb) to warm up food. For this concept 1 was given a rating of 2.

6. **Practicality**

   A weight factor of 3 was given to practicality of modelled design. Plastic is a difficult material to work with as opposed to metals that you can easily weld and beat into desired shape. Also in the real sense, attaching a solar panel directly on the box is not totally practical because it would mean always taking out the box that contains food out into the sun in order to charge the battery. For this concept 2 was given a rating of 4 while concept 1 was given 3

4. **Flexibility**

   Considering the fact that power supply in this part of the world is not always constant, the idea of having two possible heating sources became an excellent choice because this not only provides the opportunity to make use of the system on demand but it also saves power consumption/usage generally. A weight factor of 2 was given to this and for the above stated reason, concept 1 was given a rating of 2 while concept 2 was given 5.

5. **Aesthetics**

   For the course of this project, aesthetics was made to be the least important as other criteria proved to be more important. A weight of 1 was given to the category and concept 1 was rated to be 5 while concept 2 was rated to be 3.

Table 3.1: The selection of the design concept using the Decision Matrix

STANDARDS	WEIGHT	CONCEPT 1		CONCEPT 2	
		RATING	WEIGHTED SCORE	RATING	WEIGHTED SCORE
COST	5	5	25	3	15
EFFICIENCY	4	2	8	5	20
PRACTICALITY	3	3	9	4	12
FLEXIBILITY	2	2	4	5	10
AESTHETICS	1	5	5	3	3
TOTAL SCORE			**51**		**60**

Therefore concept 2 was chosen to be the most viable option for our design.

3.8. DESIGN CALCULATIONS

1. The width of the box was made to be **400mm** while the breadth was made to be **280mm** with an overall height of **230mm.** The radius of the stainless-steel food chamber was made to be **100mm.**
2. Insulation material of **20mm** thickness was placed in between walls of food warmer container to reduce heat loss to the surrounding.
3. For this system, our desired temperature and ambient temperature was given as:

   Desired temperature = **60°C**

   Ambient temperature = **32°C**

4. Cross sectional area of Box = LXB - 400mm x 280mm = **112000**$\boldsymbol{mm^2}$ = **0.112**$\boldsymbol{m^2}$
5. Cross sectional area of Stainless steel = πr^2- π x 200^2 = **125663.706**$\boldsymbol{mm^2}$ = 0.126$\boldsymbol{mm^2}$
6. Thermal Conductivity of each material through which heat is conducted:

   Mild Steel = 45 **W/ (Mk)**

   Stainless Steel = **15 W/ (mK)**

   Fibre glass = **0.36 W/mK**

   Wood dust = **0.21 W/mK**
7. Determination of heating element wattage:

   For the AC part of the system, because we want to raise the temperature of our food from ambient temperature (32°C) to our desired set value (60°C). We would need to make use to the equation

   $Q_{st} = \frac{m\ C_w \Delta T}{3600}$ … (3.8)

   Where:

   Q_{st} = the heat energy required to raise the temperature of the food from an ambient temperature value to a set value of 60°C

   C_w = the specific heat capacity of the food usually vary depending on the composition or constituents that make up the food.

   Usually the specific heat capacity of foods containing high amount to protein or carbohydrate is found to vary between 2.1 to 2.3 J/g°C. Hence an average value of **2.2 J/g°C** was set for the sake of this project work.

   Also, the average weight of food an average adult will consume ranges from 0.23kg to 0.45kg. For this project we would be assuming a food weight of **0.5kg**.

   Therefore applying the formular above, the heat energy required to raise the temperature of the food from the ambient to the set value is given as 8.555Wh

Hence to accommodate for losses and achieve heating faster with AC heating, a heating element of 1000W was chosen, however the temperature regulator which can reach temperatures of 250℃ and above was kept to regulate at (60 ± 10)℃

On the other hand, the DC heating uses a bulb of 55W to achieve this heating even though it will take longer time to attain this temperature. Due to special constraint, only one of this bulb was used even though the DC method of heating has proven to be cost effective and also saves power.

8. Determination of Rate Heat transfer through Outer Casing:

   This project not only focuses on heating up food to a desired temperature but also prioritises the extent to which this food warming system can store the heat that has been generated.

   In order to calculate this heat transfer from the inner food chamber to the outer surrounding, we would have to consider the flow of the heat through the outer surfaces of the container and make some assumptions such as:

   i. Heat flow is unidirectional.
   ii. There is perfect heat transfer between each transmitting medium.
   iii. There is uniform radiation from incandescent lamp to the food chamber

   In the process of experimenting with different foods, we were able to determine the time it takes for the food to loose heat within a temperature range and this was shown in chapter 4.

3.9. MATERIAL SELECTION

Steel can be basically characterized as an iron and carbon alloy. A metal that is created by mixing two or more metallic elements is referred to as an alloy. When it comes to steel, many alloys are created to increase the metal's overall strength and corrosion resistance. Steel is incredibly versatile and can be combined with many other elements, which has resulted in the development of more than 3500 different grades of the metal that are divided into categories depending on their unique features. These grades are defined by the metal's processing, the quantity of carbon it contains, and any other alloys that may have been added.

Steel is the best material to utilize in high-temperature situations like car or airplane engines since it has one of the lowest thermal conductivity values of all metals. Because of this ability to be used in high temperature application, **Stainless Steel (304)** was selected as our food chamber that directly receives the heat (Kallista Wilson, 2015).

Also the general outer make of our project utilises mild steel which is a material that can be easily worked on as opposed to using plastic that is cheaper and lighter.

Specifically square pipe section of mild steel were used for the body of the machine. Mild steel was chosen over stainless steel because of its machinability, ease of fabrication, availability and low cost. The material properties of mild steel are shown in the table below.

Table 3.2: The material properties of Mild Steel

Chemical composition	**Carbon, C**	**0.14-0.20%**
	Iron, Fe	98.81-99.26%
	Manganese, Mn	0.60-0.90%
	Phosphorus, P	≤0.040%
	Sulphur, S	≤0.050%
Density		$7.87 \times 10^5 kg/m^3$
Ultimate tensile strength		440Mpa
Yield tensile strength		370Mpa
Modulus of elasticity		205Gpa
Bulk modulus		140Gpa

Poisson ratio	0.290
Shear modulus	80GPa

3.10. FABRICATED DESIGN OF A FOOD WARMER

The fabrication of the designed system was carried at the Foundry Workshop of the Faculty of Engineering in the University of Benin. The Fabricated design is shown in the figures below:

Fig 3.8: The first image of the fabricated prototype

Fig 3.9: The second image of the fabricated prototype

3.11. DESIGN PROCESS

1. **Marking out:** This is the process of transferring the dimension of the design from the model specification to the work piece. This was the first operation carried out when trying to produce a part. It was carried out with the help of measuring type, try-square and chalk.
2. **Cutting:** After marking out operation, the part was cut from the work piece. This was achieved with the help of a hacksaw and angle grinder. An allowance was usually given during the marking out operation in other to account for the thickness of the cutter.
3. **Welding:** This was the primary joining operation carried out during the course of the fabrication. The type of welding employed was electric arc welding. Two different electrode types where used: gauge 12 for tacking while gauge 10 afterward for making the joints permanent.

3.12. MATERIALS USED FOR FOOD WARMER

1. Dry Cell D.C Battery:

Fig. 3.10: Lead acid batteries

12 volt dry cell DC battery was used to power the heating element. The specification are shown below.

Table 3.3: The specific details of the dry cell battery used in the experiment

Type		**Lead acid**
Quantity		4PC
Weight		1.5kg
Nominal voltage		12V
Nominal capacity (20 hours ratio)		18Ah
Dimensions	**Length**	364mm
	Weight	200mm
	Total height	190mm

2. **AC Heating Element (Tungsten Wire):**

The AC heating element in the portable food warmer utilizes a tungsten wire. Tungsten is an ideal choice for AC heating due to its high melting point and excellent electrical conductivity. When an alternating current passes through the tungsten wire, it rapidly heats up, providing consistent and efficient heating for the food warmer. Tungsten's durability ensures a long lifespan for the heating element.

Fig. 3.11: Heat element, tungsten for A.C

3. **DC Heating Element (Mobile Filament):**

The DC heating element in the parable food warmer relies on a mobile filament. This filament is designed to operate with direct current (DC) power sources, making it suitable for use with batteries or mobile power supplies. The mobile filament is typically made from materials that efficiently convert electrical energy into heat. It offers portability and flexibility, allowing the food warmer to be used in various settings, including outdoor or mobile applications.

Both heating elements play a crucial role in maintaining the desired temperature in the food warmer, ensuring that your meals stay warm and ready to enjoy.

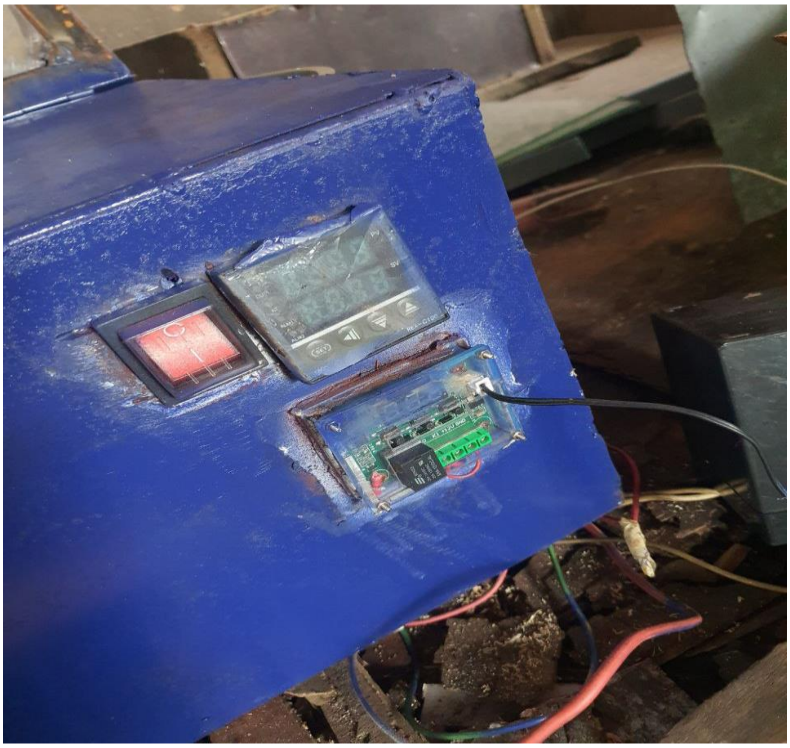

Fig. 3.12: The Power switch and temperature controllers

In the context of a portable food warmer, switches play a critical role in controlling the device's heating element and ensuring user convenience and safety. Here is how switches are relevant to a portable food warmer.

4. **Power Switch:**

   The most basic function of a switch in a portable food warmer is to act as a power switch. This switch turns the entire device on or off. When you want to heat your food, you toggle the power switch to the "on" position, allowing electricity to flow through the heating element. When the food is adequately warmed, or you no longer need the warmer, you switch it to the "off" position to cut off power, preventing unnecessary energy consumption.

5. **Temperature Control:**

   Some advanced portable food warmers include temperature control switches. These switches allow users to select and adjust the desired temperature for warming their food. Depending on the type of food and personal preferences, you can increase or decrease the temperature using this switch. This feature is especially useful for keeping different types of food at their ideal serving temperatures.

6. **Safety Switches:**

   Safety is paramount when it comes to portable food warmers. These devices may include safety switches or mechanisms that prevent overheating. If the internal temperature of the food warmer exceeds a safe threshold, a safety switch can automatically turn off the heating element to avoid damage or potential hazards.

7. **Indicator Lights:**

   Many portable food warmers come with indicator lights that show whether the device is on or off. These lights are often integrated with the power switch, providing a visual cue to users about the status of the warmer. This helps users avoid accidentally leaving the device on when not in use.

8. **On/Off Delay:**

   Some food warmers have a switch that incorporates an on/off delay. This feature ensures that the heating element doesn't turn on immediately after the device is powered up. It allows the warmer to stabilize before starting the heating process, which can improve energy efficiency and prevent sudden temperature spikes.

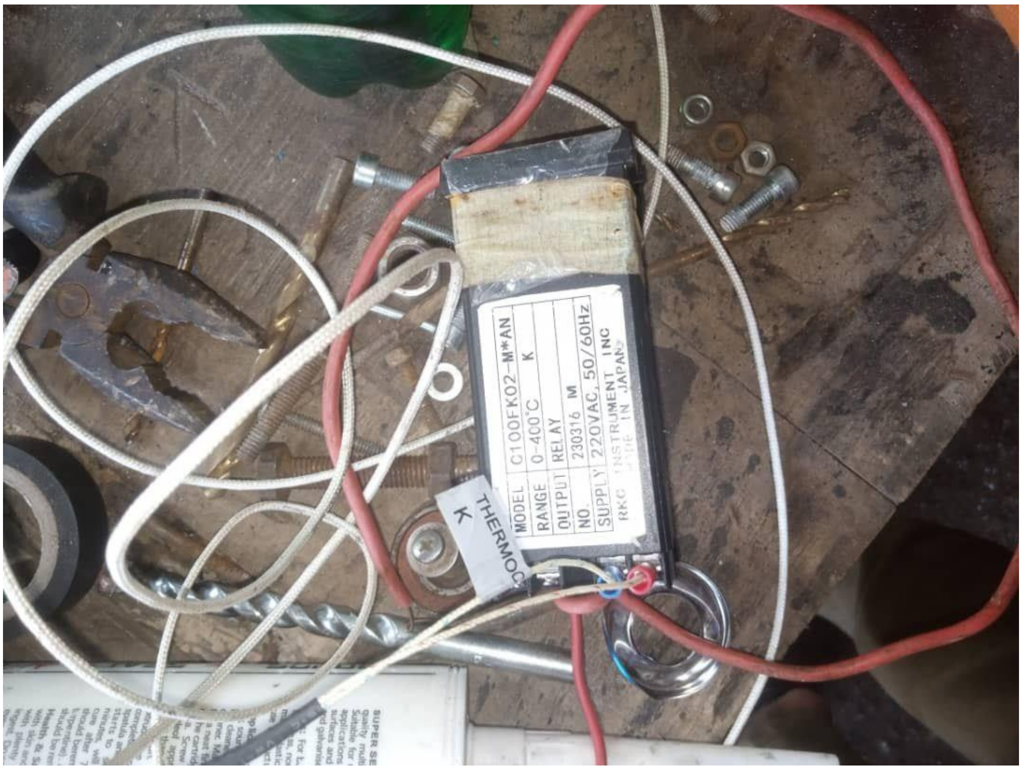

Fig. 3.13: P.I.D controller and Relay for AC Temperature controller

9. **P.I.D Controller:**

   This setup allows the Proportional Integral Derivative (PID) Controller to monitor and control the temperature of the food warmer, ensuring that it maintains the desired temperature for keeping food warm. Always consider safety precautions when working with AC circuits and ensure proper insulation and grounding to prevent electrical hazards.

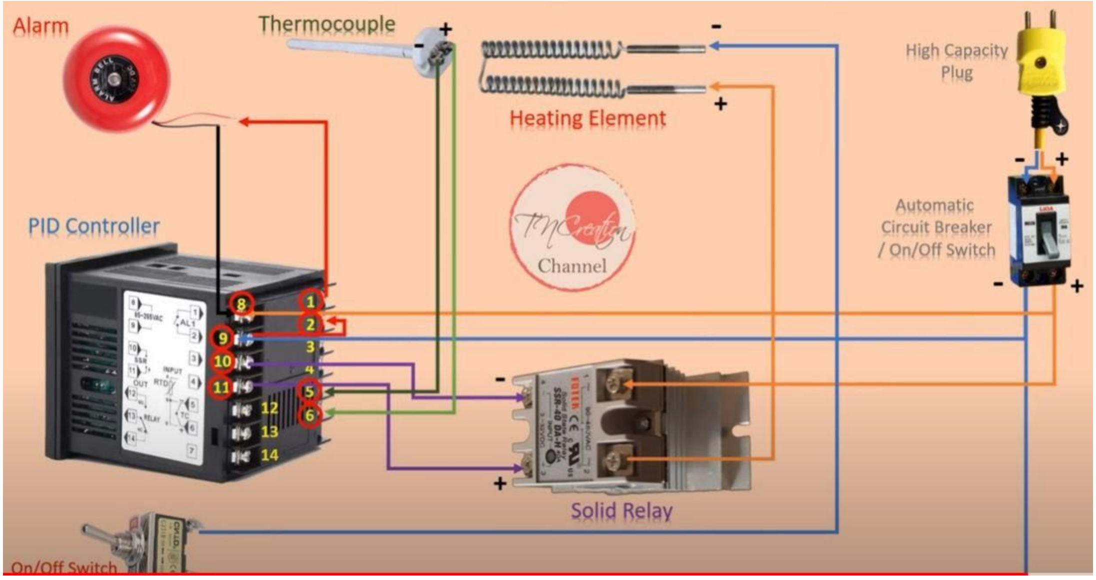

Fig. 3.14: Diagram of system and its components

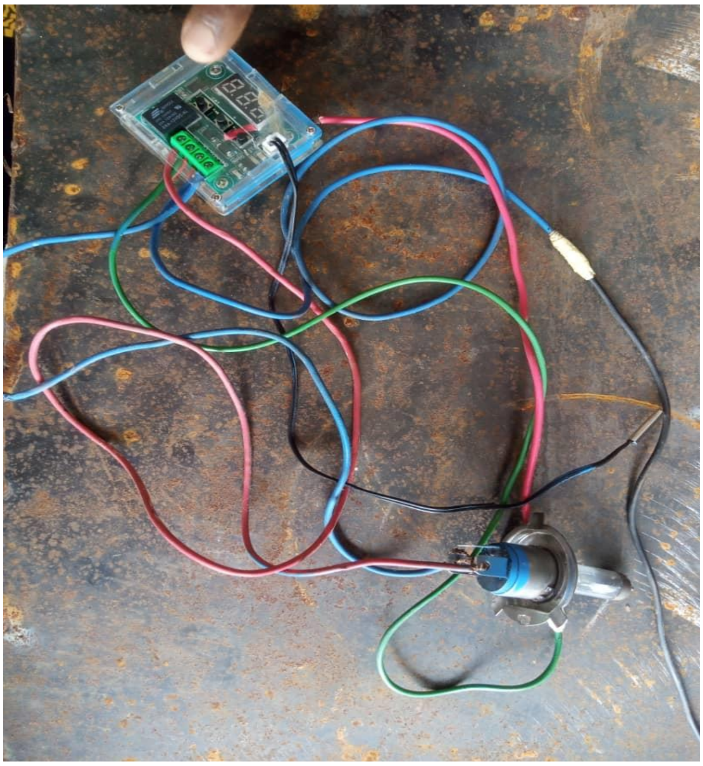

Fig. 3.15: DC heating element (Using Incandescent bulb)

In summary, switches in a portable food warmer serve to control its power, temperature settings, and safety features. They make it easy for users to operate the warmer, customize their food-warming experience, and ensure that the device operates safely and efficiently.

10. Mild steel

Mild steel is utilized in portable food warmers primarily for its strength, cost-effectiveness, ease of fabrication, and corrosion resistance. It provides structural integrity and can withstand moderate heat, making it suitable for various components while also keeping manufacturing costs reasonable. However, its usage depends on the specific design and intended application of the food warmer.

Fig. 3.16: The external surface of the system made of Mild Steel

11. Stainless steel

Stainless steel is an ideal material for portable food warmers due to its food safety, heat resistance, corrosion resistance, aesthetics, and ease of maintenance, durability, and versatility. It ensures that the food warmer not only performs its function effectively but also remains safe, visually appealing, and long-lasting.

Fig. 3.17: The internal compartment of the system made of stainless steel

CHAPTER 4

ANALYSIS, RESULTS AND DISCUSSION

4.1. RESULTS

The basics analysis of our food warmer was to check the time different foods took to reach the set temperature value for both AC and DC. Also to determine the extent per time to which the heat is stored in this closed system without falling below the safe temperature range.

Temperature regulators were installed in the food warmer system that makes it easy to take the temperature reading of the item contained in the food chamber using a thermocouple.

For the testing, we examined 3 different items;

1. Cup of water
2. Locally made meat pie
3. Cooked Rice

Results gotten after examining the performance of temperature change over time for the items above is displayed below –

4.1.1. A.C TEST

Table 4.1: Readings derived from the A.C heating experiment using Water

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
35.60	60.00	6.70	83.00	27.00
34.50	60.00	7.00	83.00	27.00
34.00	60.00	7.01	83.00	27.00

32.00	60.00	7.03	83.00	27.00
30.00	60.00	7.10	83.00	27.00

Table 4.2: Readings derived from the A.C heating experiment using Meat Pie

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
37.00	60.00	6.34	81.00	26.00
35.00	60.00	7.40	81.00	26.00
35.00	60.00	7.21	81.00	26.00
36.00	60.00	6.37	81.00	26.00
35.50	60.00	7.17	81.00	26.00

Table 4.3: Readings derived from the A.C heating experiment using Cooked Rice

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
40.00	60.00	5.90	81.00	27.00
42.00	60.00	5.85	81.00	27.00
39.00	60.00	6.73	81.00	27.00
40.00	60.00	5.92	81.00	27.00
45.00	60.00	4.70	81.00	27.00

4.1.2. D.C. TEST

Table 4.4: Readings derived from the D.C heating experiment using Water

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
35.00	60.00	22.00	70.00	10.00
34.60	60.00	22.06	70.00	10.00
34.50	60.00	22.11	70.00	10.00
31.00	60.00	23.02	70.00	10.00
30.00	60.00	23.00	70.00	10.00

Table 4.5: Readings derived from the D.C heating experiment using Meat Pie

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
35.50	60.00	20.10	66.00	11.00
35.10	60.00	20.05	66.00	11.00
34.00	60.00	20.11	66.00	11.00
32.50	60.00	20.20	66.00	11.00
31.00	60.00	20.29	66.00	11.00

Table 4.6: Readings derived from the D.C heating experiment using Cooked Rice

Start temperature ºC	Final temperature ºC	Time (min)	Max temperature ºC	Time (min)
36.00	60.00	21.00	68.00	9.00
35.50	60.00	21.07	68.00	9.00
35.00	60.00	21.10	68.00	9.00
33.00	60.00	21.16	68.00	9.00
32.00	60.00	21.20	68.00	9.00

4.2. DISCUSSION

4.2.1. A.C TEST

As shown in tables 4.1, 4.2 and 4.3, it took an average of 7 minutes for the food item to reach the final temperature of 60ºC. The temperature controller was set to have a hysteresis error of 1.00 this means that the system would shut off when the temperature reached the set value of 60ºC and comes back on when the temperature drops to 59ºC.

1. Overshoot of Temperature Controller

During the experiment, we observed an overshoot of 10 to 15ºC when the temperature of the food item reaches the set value, this means that the temperature keeps increasing to values like 70 to 75ºC even when the heating element has been shut down. The reason for this is because the heat generated by the heating element is very high and that of the food is relatively low, so even if the heating element loses temperature to the surrounding, the food in the food chamber is still gaining this heat.

2. Temperature drop with time

Table 4.7: Temperature drop with time for the A.C test using the Meat Pie test as a case study

Temperature drop (ºC)	Time (min)
81.00	4.00
78.00	10.00
76.00	14.00
74.00	19.00
72.00	22.00
70.00	26.00
68.00	29.00
66.00	37.00
63.00	44.00

After the maximum temperature has been reached, we observed the gradual drop in temperature over time when the system is tightly closed.

The graph below was plotted to show this gradual decrease.

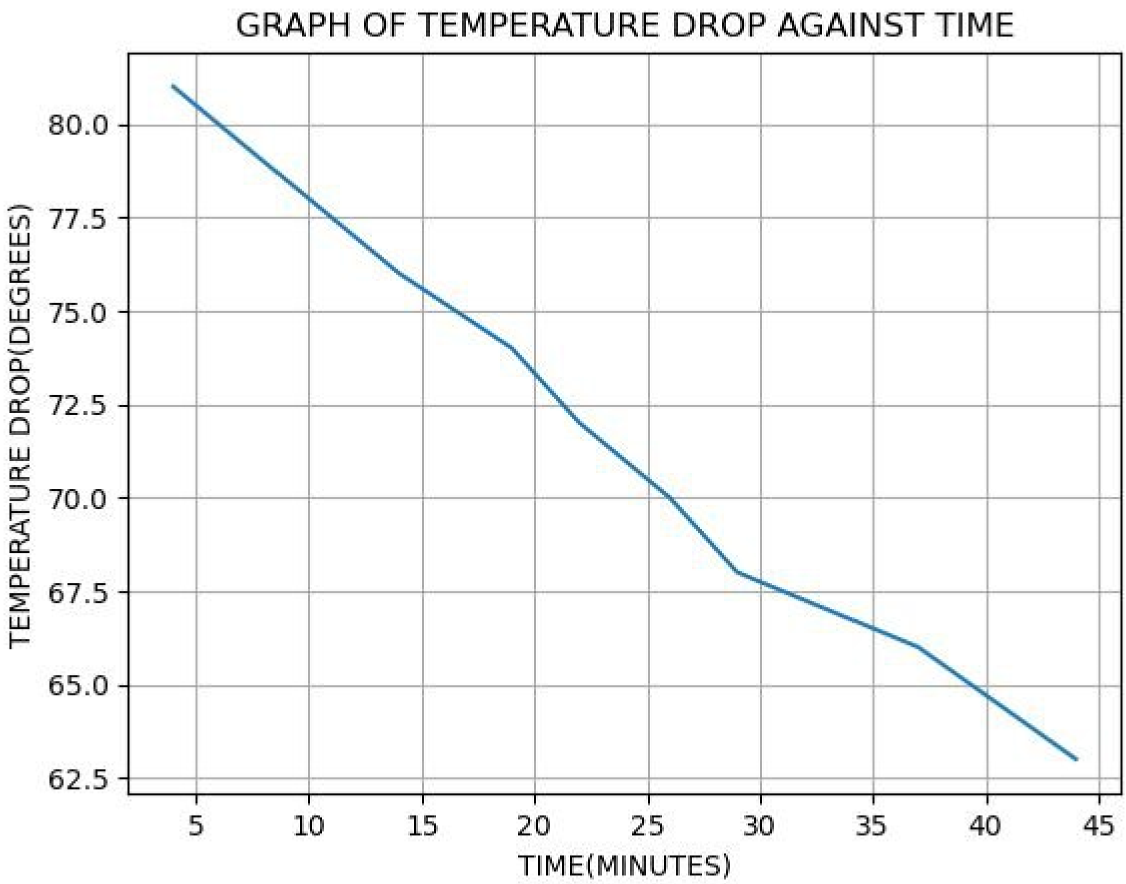

Fig. 4.1: Graph of Temperature drop with time for the A.C test

Form the graph above, it can be seen that there is a slow decrease in temperature before if reached the point where the system turns on again. From this we can attribute the slow reduction of heat to the effectiveness of the insulated walls of the food warmer container.

4.2.2. D.C TEST

As shown in the tables 4.4, 4.5 and 4.6 above, it took about 20 to 22 minutes for the food item to get to the set temperature. The temperature controller was set to have a hysteresis error of 1.00 this implies that the system would shut off when the temperature reached the set value of 60ºC and come back on when the temperature drops to 59ºC.

1. Overshoot of Temperature Controller

During the D.C experiment, an overshoot of 6 to 10ºC when the temperature of the food item reaches the set value was observed, this means that the temperature kept increasing to values such as 66 to 70ºC even when the heating element had been shut down. The reason for this was because the heat generated by the heating element was very high and that of the food is relatively low, thus even if the heating element lost temperature to the surrounding, the food within the inner chamber still gained this heat.

2. Temperature drop with time

The temperature drop with respect to time using the rice test was also observed as shown in the table below:

Table 4.8: Temperature drop with time for the A.C test using the Cooked Rice test as a case study

Temperature drop (ºC)	Time (min)
68.00	3.00
67.00	6.00
66.00	9.00
65.00	12.00
64.00	15.00
63.00	17.00
62.00	19.00
61.00	21.00

After the maximum temperature has been reached, we observed the gradual drop in temperature over time when the system is tightly closed.

The graph below was plotted to show this gradual decrease.

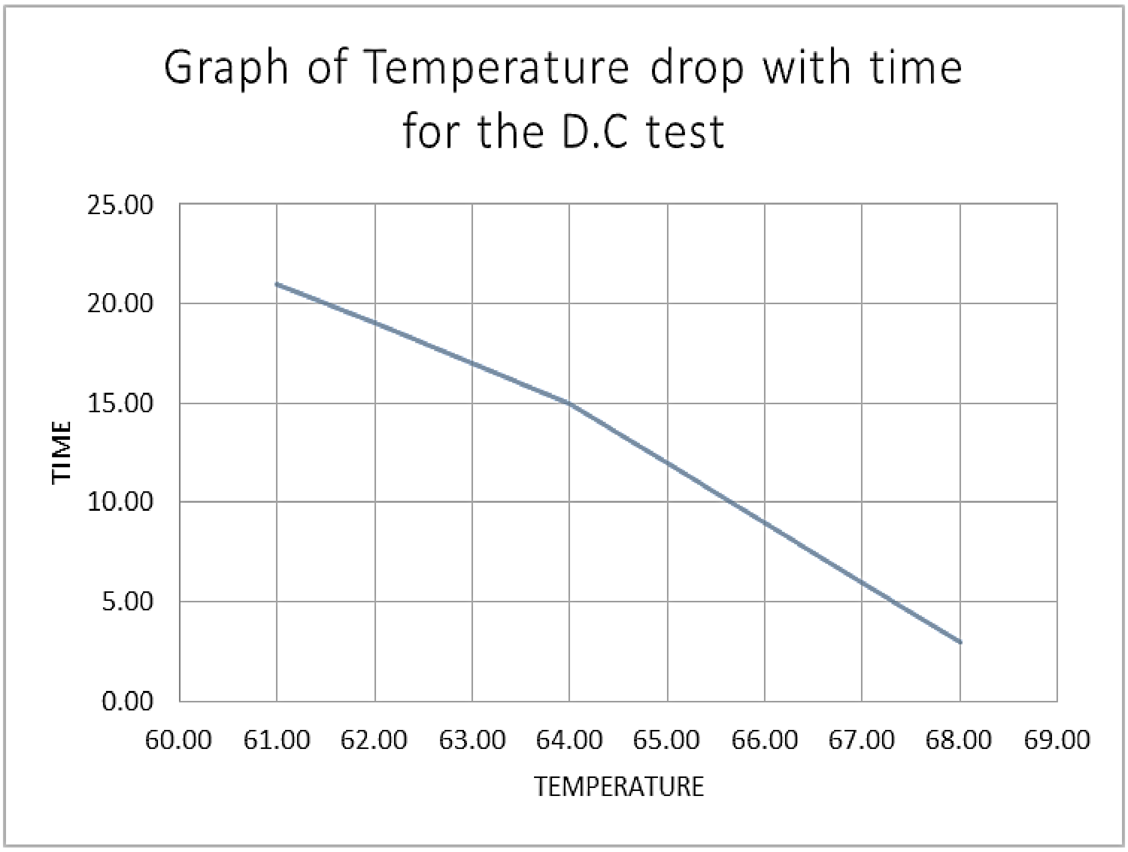

Fig. 4.2: Graph of Temperature drop with time for the D.C test

From the graph above, it can be observed that there was a slow decrease in temperature before it reached the point where the system turns on again. From this we can therefore also attribute the slow reduction of heat to the effectiveness of the insulated walls of the food warmer container.

4.3. PERFORMANCE EVALUATION

A physical model of the Food Warming System was fabricated and tested in the Faculty of Engineering, with both tests carried out at separate times. The A.C heating experiment was conducted on the evening of Monday the 25th of September, and the D.C heating experiment was conducted on the afternoon of Thursday the 28th of September, 2023.

During the A.C test, it was observed that a lot of time was taken for the temperature to drop to set value, approximately 45minutes elapsed before the temperature was able to get back to the set value of 60ºC from a maximum temperature of 83ºC. The same occurred during the

D.C test in which the temperature dropped to the set value after approximately 23 minutes after it had earlier attained a maximum temperature value of about 70ºC. However, at elevated temperatures the outer compartment of the system began to heat up as a result of the immensely high temperature of the heating elements but for the sake of this project the temperature is set to regulate between 60ºC and the over shoot of 10ºC.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

In this work, the primary concept was to preserve the quality of food by regulating it at safe temperature range and storing up the generated heat. Also the possibilities of 9-5 workers to have a permanent solution to preserving their home-made food after several working hours. The system is portable enough to be used remotely and carried to several locations where the traditional solar cookers or conventional microwave will be limited.

For the Alternating Current test, the maximum temperature reached by our food warming system was found to be 83ºC in an average time of 27 minutes while it reached the set value of 60ºC in an average time of 7mins; that of then Direct Current test was a maximum temperature of 70ºC in an average time of 11 minutes while it reached the set value of 60ºC in an average time of 22 minutes. The time taken for the food temperature to drop to the set value for the A.C and the D.C tests were approximately 45 minutes and 23 minutes respectively.

Therefore, the system is capable of not only reheating the food but also preserving the food’s temperature for a long period of time.

5.2. RECOMMENDATIONS

Due to financial constraints, a bulb with a higher power output would have been purchased to fast track the heating process of the DC part of the system. Also a solar panel would have been bought to increase the speed at which the battery gets charged for reuse. Other recommendations include:

1. Use of a longer thermocouple for the DC system in order to be as close to item and not DC bulb.

2. Making the food chamber detachable for maintenance and also quenching in water as the previously heated food chamber may affect results gotten for another food item.

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