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Economic Design, Fabrication, and Performance Evaluation of Conventional Ovens Made of Glass-Fiber-Reinforced Thermoset Composites

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Abstract

This study focuses on the development of a conventional oven using glass-fiber-reinforced thermoset composite sandwich panels. The design process considers the thermomechanical properties of the selected materials. The constructed rectangular box oven has the overall dimensions of 450 mm × 450 mm × 600 mm and internal heat chamber dimensions of 400 mm width, 400 mm depth, and 400 mm height with two stack trays for product placement. The sidewalls consist of inner and outer E-glass-fiber-reinforced composite panels with a sandwiched rockwool insulator. The bottom panel of the oven has an inner ceramic tile plate to suspend the electric heating element. The top panel is made of the same composite sandwich with a constructed superstructure electrical wiring compartment included for the controls. The oven can stably achieve a temperature of 150 °C and a cooking efficiency of approximately 39% when in operation and can sustain heat for more than 6 h standing time when turned off. The oven can be used for both culinary and laboratory experiments, i.e., heating, baking, drying, and curing materials, and is more affordable than alternative designs in the market.

Abstrak

Rancangan Ekonomis, Fabrikasi, dan Evaluasi Kinerja Oven-Oven Konvensional yang Dibuat dari Komposit-Komposit Termoset yang Diperkokoh dengan Serat Kaca. Kajian ini memfokuskan pada perkembangan suatu oven konvensional yang menggunakan panel-panel lapisan komposit termoset yang diperkokoh dengan serat kaca. Proses rancangan mempertimbangkan sifat-sifat termomekanis bahan-bahan yang dipilih. Oven kotak empat persegi panjang yang dibangun memiliki dimensi 450 mm × 450 mm × 600 mm dan dimensi ruang panas bagian dalam adalah lebar 400 mm, kedalaman 400 mm, dan tinggi 400 mm dengan dua tumpukan baki untuk penempatan produk. Dinding-dinding sisi terdiri atas panel-panel komposit dalam dan luar yang diperkokoh dengan serat kaca E dengan suatu isolator rockwool berlapis-lapis. Panel bawah oven memiliki suatu pelat ubin keramik dalam untuk menahan elemen pemanas listrik. Panel atas dibuat dari lapisan-lapisan komposit yang sama dengan suatu ruang kawat listrik yang dibangun dengan struktur super yang dimasukkan untuk pengendalian. Oven tersebut dapat mencapai suatu temperatur 150 ºC dengan stabil dan suatu efisiensi memasak mendekati 39% ketika beroperasi dan dapat menahan panas selama lebih dari 6 jam setelah oven dimatikan. Oven tersebut dapat digunakan baik untuk eksperimen kuliner maupun laboratorium, yaitu, memanaskan, memanggang, mengeringkan dan mengeraskan bahan-bahan, dan jauh lebih terjangkau dibandingkan dengan rancangan-rancangan alternatif yang ada di pasaran.

Keywords: conventional ovens, cooking efficiency, economic design, oven considerations, thermoset composites

1. Introduction

Ovens are specially designed heat chambers meant to serve designated heating or drying functions. Ovens have been used for decades for various purposes, i.e., culinary activities (e.g., food cooking, defrosting, warming, baking, and roasting) and industrial and laboratory functions (e.g., curing, drying, heat treatment, and tanning of materials). Food is cooked by the application of heat, which may be either dry or moist to make the food more palatable, render the food more digestible, give the food a characteristic taste or different tastes, and sterilize the food either partially or completely. Ovens have different shapes, sizes, and types. Ovens can be classified on the basis of the type of energy source that they use for operation (i.e., solar, fuel, and electric ovens) or the working principle (i.e., standard or conventional, convection, microwave, rack, conveyor, and rotisserie ovens or combinations of these). Energy sources for ovens include solar energy, wood, charcoal, coal, gas, and electricity. Ovens are usually made of materials with favorable high-temperature properties and low thermal expansivity. Oven temperatures normally range from ambient to as high as 500 ℃, above which it becomes a furnace [1]. The basic components of ovens include the paneling material, insulation material, heating element, control box containing the timer and thermostat, and other electrical and electronic components that serve to monitor, regulate, and control the temperature of the oven according to the desired operations. The material from which the oven chamber walls are made and the thickness of the walls are important considerations in keeping as much thermal energy in the oven chamber as possible and maintaining the outer surface within a safe temperature (industry standard of 330 K) in the event of skin contact [2,3].

To ensure high efficiency and low energy losses, ovens are usually packaged properly with good insulation materials. This reduces heat losses to the environment by conduction, convection, and radiation. The heating element is also essential for the functioning of an oven; thus, it could be considered the most important component of an oven. The heating element used for electric ovens is an air heater that converts electricity to heat through resistance heating. The speed of heating and the amount of power consumed by the oven depends on the capacity of the heating element. The standard electric oven employs three modes of heat transfer to heat the product within the chamber. A standard oven is used in this study as it has been observed that forced convection ovens diminish the utility of certain products, including food desirability and taste [4]. When the oven is switched on, the element becomes hot and heats the surrounding air and inner walls of the chamber. The heated air expands and becomes lighter in weight, thus rising to the product by convection and heating both the product and container. The heat from the container reaches the product by conduction [5]. Moreover, radiant heat from the element and inner walls of the oven reaches the product or container directly.

As a commercial oven system of an appropriate size and function will cost thousands of dollars to import, a low-cost, portable oven with variable temperature of up to 150 ℃ needs to be produced using locally available and affordable materials. The oven should ensure that heat is uniformly distributed throughout the oven enclosure, minimize all possible heat losses in the oven through the use of appropriate lagging material, maximize the efficiency of the oven through the use of an efficient heating source to achieve the best performance, and minimize the cost of maintenance. Therefore, a standard electric oven made of composite materials is considered in this study to meet the aforementioned requirements.

The literature is inundated with different designs of heat ovens made of steel, wood, and masonry materials and powered by fuel or electricity. Egware *et al*. [6] developed a sawdust-powered oven, whereas Kulla *et al*. [7] designed and constructed a small-scale charcoal baking oven using mild steel sheet. They posited that charcoal produces heat that is hotter and burns cleaner than wood, making it ideal for cooking both in rural and urban settlements for domestic consumptions and small-scale businesses. Genitha *et al*. [8] designed, fabricated, and tested a domestic gas oven made of stainless steel outer casing and aluminum sheet inner casing with silicone rubber and asbestos insulator to avoid rusting and ensure easy cleaning and heat retention, respectively. Although wood and gas fuel energy supplies may seemingly look economically cheap compared with electric ovens, they have high emissions of gaseous pollutants, including carbon monoxide and nitrogen oxides [9]. Akinyemi [10] and Olugbade and Ojo [11] produced and tested standard electric ovens made of mild steel paneling. Adegbola *et al*. [12] enhanced the design and construction of the basic domestic electric oven through the incorporation of a blower to improve hot air circulation and an interlock switch to ensure safe operation. Ameko *et al*. [13] designed and constructed a portable wooden box electric dehydrator using plywood panels. The chamber is heated by 100 W incandescent bulbs with the warm air circulated by a fan. Okafor [14] and Adeyinka *et al*. [15] developed an oven with a dual-energy source for heating the oven chambers. The upper chamber is powered by electricity, whereas the lower chamber is powered by heat supplied from cooking gas located outside the chamber. In a related development, Chukwuneke *et al*. [16] developed a dual-powered mini oven that has the electric heating coil and gas burner in one chamber and alternately deployed during use. David *et al*. [17] developed a microcontroller-based electric cooker/oven with time and temperature controls and an ATmega8 microcontroller as the core component. The microcontroller enables the cooker/oven to conserve energy by switching off as the set time elapses. Cen-Puc *et al*. [18] designed, constructed, and thermally characterized a dedicated electric oven made of quartz tube having solid aluminum lids with proportional–integral–differential loop control. This electric oven was used specifically for the characterization of small thermo-resistant polymer nanocomposites. Although the functional capability of these added advanced controllers was discussed, the cost implications were not indicated. Ramezankhani *et al*. [19] conducted a feasibility study to explore and select alternative designs and materials for a mobile food truck tandoor oven so that it will have better thermal properties, such as high specific heat capacity, moderate thermal diffusivity, appropriate durability (not too brittle for transportation), and lightweight. They observed that materials used for thermal insulation are characterized by low thermal conductivity, which is obtained through the use of air pockets as in the case of polymer foams, glass fiber felts, and porous ceramics.

Therefore, a good design of a standard heat oven must be a combination of the appropriate heat source within the oven chamber and the right materials for the construction of the oven. Notably, electric resistance heating has various advantages over systems based on fuel combustion, such as increased control accuracy and heating rate. Thus, electrical resistance heating provides a more suitable means for developing laboratory ovens, particularly for those demanding small heating volumes and precise temperature control [16,18]. Despite the avalanche of designs presented in the literature, the use of composite panels is yet to be practically demonstrated. An oven fabricated using composite material is expected to have some superior properties to those fabricated using some other materials, such as metal and wood. These preferential properties include lightweight, corrosion resistance, ease of fabrication into curved shapes for easy maintenance and esthetics, and excellent damping and insulation of heat and electricity. Therefore, this study aims to design and construct an electric oven using thermoset composite sandwich panels.

2. Methods

Oven design considerations. The following were considered in the design of the oven: quantity of products to be processed at a time, thermophysical properties of the processed product, and uniformity, size, and shape of the product. Small-sized laboratory samples and family-sized culinary needs informed the choice of a 400 mm × 400 mm × 400 mm oven chamber size as being adequate, which also compares well with what already exists in the market. A low-cost, portable conventional oven of less than 20 kg net weight was targeted.

The thermomechanical properties of the oven materials (see Table 1) define the oven heating capacity, the temperature tolerance that is permissible for the oven, and the necessary controls. A maximum temperature of 150 ℃ was set to avoid material deterioration. A 220–240 V/50 Hz single-phase electricity supply was designed for the oven. The heating element was placed over the base of the heating chamber to enhance heat flow distribution. The trays had a wire mesh geometry that enables even temperature distribution in the oven. Thermostatic control and fuses were selected to ensure safe operation and reduce procurement costs. Glass-fiber-reinforced laminate was selected for the paneling because of its high strength-to-weight ratio, good insulation, and corrosion-resistant property compared with other commonly used materials (see Table 1). A glass wool sandwich was also considered for adequate insulation. Standard sizes of the materials were selected to ensure cost reduction and affordability.

Table 1. Comparison of the Desired Properties of Glass-fiber-reinforced Polymer Composite [20]

Material	Density (kg/m^3)	Tensile Strength (MPa)	Thermal Conductivity (W/m·K)	Relative cost
Glass fiber laminate	1,494.7	103.40	0.2020	1.00
Mild steel	7,805.8	206.84	46.15	0.26
Stainless steel	7,896.4	220.06	128.3	2.77
Aluminum	2,712.6	82.4	191.83	2.32

Heat transfer and estimation of power requirement in the oven. In the oven, convection, radiation, and conduction heat transfers occur. Convection occurs when heated air surrounding the heating element in the oven expands, becomes less dense, and ascends, whereas the cooler and denser air descends. This cycle continues until the heating stops. Radiation occurs between the heating element and the internal surrounding of the oven to heat the specimen in the oven. Conduction occurs when the tray in the oven becomes hot and transfers heat energy to the specimen in contact with it. However, this mode of heat transfer is negligible compared with the two other modes because the tray is thin. In this study, the appropriate material and insulation thickness were selected to reduce the heat losses considerably.

The estimation of the power requirement is done using steady-state analysis of the heat required to maintain the temperature inside the oven at 200 ℃ above the 150 ℃ operational requirement to account for incidental low supply voltages. The steady-state analysis estimates the required heat to account for the heat losses from the oven while in operation, which are considered the losses through the oven walls by conduction [2].

According to Fourier's law of heat conduction, the rate of heat flow can be derived as follows:

$$\dot{Q} \propto A\frac{\Delta T}{\Delta L}$$
$$\dot{Q} = -KA\frac{T_{in} - T_{out}}{L} = -A\frac{T_{in} - T_{out}}{R} \quad (1)$$
$$R = L/K$$

where R is the thermal resistance of the oven box, K is the thermal conductivity of the wall material (W/m·K), A is the surface area of the oven across which heat is lost to the environment (m^2), T_{in} is the oven chamber temperature (K), T_{out} is the temperature of the environment (K), and L is the thickness of the oven wall.

The sidewalls and top of the oven are made of 3 mm inner and outer composite panels with sandwiched 24 mm thick glass wool, whereas the bottom cover has an additional ceramic tile protector on its inner part forming the floor. Therefore,

the sidewall resistance: $R_s = R_c + R_g + R_c$ on each side,

the top ceiling resistance: $R_t = R_c + R_g + R_c$,

the bottom floor resistance: $R_b = R_T + R_c + R_g + R_c$,

where the subscripts T, c, and g denote the tile, composite laminate, and glass wool, respectively.

Considering the cuboidal design and neglecting the unsealed electrical wiring compartment heat transfer, we have the power requirement, $P = \dot{Q}$, which can be derived as follows:

$$\dot{Q} = A(T_{in} - T_{out})\left(\frac{5}{2R_c + R_g} + \frac{1}{R_T + 2R_c + R_g}\right) \quad (2)$$

with $A_s = A_t = A_b = A$ where the subscripts s, t, and b denote the side, top, and bottom, respectively.

The data used in Eq. (2) are as follows: A = 0.45 m × 0.45 m = 0.2025 m^2, L_c = 0.003 m, L_g = 0.024 m, L_T = 0.008 m, K_c = 0.2020 W/m·K, K_g = 0.04 W/m·K, and K_T = 0.840 W/m·K.

The power requirement was calculated to be 333 W, which is well below the available low-cost heater capacities in the market. A higher-capacity heater was obtained, which will quicken the heating up of the oven chamber and account for other heat losses that might occur through infiltrations.

Materials. E-glass-fiber-reinforced polyester composite sheets are used for both the outer and inner casings. E-glass-fiber-reinforced polyester composite sheets have a good strength-to-weight ratio and poor conductivity (see Table 1), thereby making them suitable for portable design and heat retention. The inclusion of reinforcements into polymers enhances the thermal stability and lowers the thermal decomposition of laminates [21,22]. Corrosion resistance and ease of formability were equally useful design considerations that favored the GFRP. The refractory material used is a 400 mm × 400 mm ceramic tile. The refractory material retains its physical and chemical stability at high temperatures and has an unusually high melting point, low coefficient of expansion, and low thermal and electrical conductivity. These properties help the refractory material avoid cracking due to the high differential between the rates of expansion and contraction of the material surface directly in contact with heat compared with their interior molecules or particles. The refractory material is placed directly below the heating element to protect the polymer composite from direct contact, minimize heat loss, and reflect the heat within the oven. Glazed tile is selected to ensure easy cleaning in the event of spills.

Heating elements of 1.0 kW (40.5 Ω) and 0.8 kW (65.6 Ω) with spread-out shapes are the sources of heat. The heating element works on the principle of electric current resistance. The heating element used for electric ovens is an air heater that converts electricity to heat through resistance heating. The speed of heating and the amount of power consumed by the oven depends on the capacity of the heating element. Glass wool is the major insulation material. The insulation material comes with a sheet of aluminum foil placed on one side of the glass wool sheet, and this part is installed in such a way that it faces the inner direction of higher temperature. The insulation material prevents heat loss by lagging and reflection.

The temperature regulator works using a thermostat assembly and on the principle of a thermostat, i.e., using a bimetallic strip that functions to maintain a steady temperature. Once there is an electric power supply, when the control knob is turned from the zero position to select the desired temperature, the temperature of the device increases. As the oven reaches the desired temperature, the bimetallic strip in the thermostat expands in such a way that it loses contact, thereby breaking the circuit. As the heating elements cool, the strip contracts and makes contact again, thus switching on the electrical circuit once more. This make-and-break device regulates the temperature of the heating coil to any setpoint temperature needed at any moment by tripping off. It waits until the oven temperature goes back to normal, and contact is made again to heat up to the required temperature. The indicator light indicates the flow of electric current in the oven. The fuses serve as a circuit breaker in the case of a dangerous electric power surge. Other materials are trays in mesh form in which the products are placed. Handles and supports are installed for the portability and positioning of the oven.

Major tools and equipment used in the design and fabrication processes include a scriber used to mark layout and cutting lines, scissors used to trim the glass fiber ply, measuring tape used to take linear measurements, remote and mercury thermometers used for temperature readings, drilling machine used to precisely drill holes to exact depths, a file used to cut fine amounts of material from the laminate sheet, sandpaper used to remove small amounts of material from the surface of the workpiece, grinding machine used to cut the laminate sheet into the required size, brush used to apply the resin mix to the glass fiber, and

SUMEC FIRMAN SPG3000 electric generator for the necessary and guaranteed uninterrupted power supply. Other tools include pliers, screwdriver, masking tape, and bowl. The personal protective equipment used includes an overall, nose mask, earplug, goggles, safety glasses, and gloves.

Method. Glass-fiber-reinforced composite laminates with a thickness of 3 mm were produced from E-glass fiber and unsaturated polyester resin using the wet lay-up technique. The laminates were produced using 2,400 mm × 1,200 mm × 4 mm flat mild steel sheet mold. The cured laminates were trimmed to remove the flashings. These laminates were used alongside the glass wool insulation sandwiched in between to create 30 mm sandwich panels. For the external casing of the oven, four pieces of 600 mm × 450 mm were cut to account for the vertical external faces. Moreover, for the external faces, two pieces of 450 mm × 450 mm were cut to account for the bottom of the oven and seating for the electrical circuit compartment. The compartment was provided with a 400 mm × 210 mm top cover for easy maintenance. The top of the oven enclosing the electrical wires has its sides constructed with a corner radius of R100 to enhance its esthetic value. For the internal chamber, five pieces of 400 mm × 400 mm were cut to account for all its faces, except for the front door. The front door is a 450 mm × 450 mm × 30 mm sandwich panel. Strips of 450 mm × 30 mm × 3 mm were used to trim the sides of both the door and door opening.

The oven box assembly was constructed using the cold welding process. The edges of the cut FRP were cleaned with a rag to ensure proper adhesion. With cello tape, the external and internal box-like casings were created temporarily. The box-like structure was held in place by applying the prepared mixture of resin, catalyst, and accelerator from the opposite sides of the cello-taped joints. E-glass fibers were added to these faces and properly infiltrated with the resin matrix to ensure rigidity. The tapes were removed when the mixture cured properly on the joints. The energy loss problem in the oven was solved by proper insulation using glass wool. The glass wool was installed in between the outer and inner casings. The glass wool has two faces, i.e., the lagging and reflecting parts. The glass wool reflector made of aluminum foil enhanced the effectiveness of heat retention within the chamber by facing it toward the inside of the chamber.

Electrical fittings were made of conduits and compartmental electrical circuits located on top of the oven with the outlet connection to the mains located below at the back of the oven for safety. The analog dials of the temperature regulator with indicators, cut-out fuses, and indicator lamp were installed at the front top of the oven for easy access and monitoring. Figure 1 shows the electrical circuit diagram of the oven.

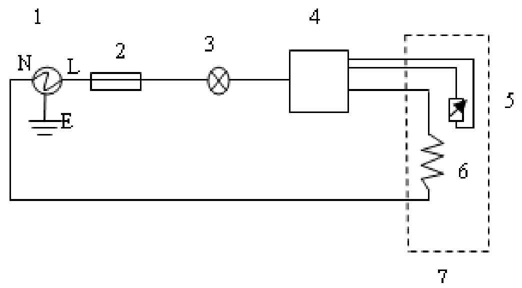

Figure 1. Electrical Circuit Diagram of the Heat Oven: (1) 220 V, 50 Hz Supply, (2) Fuse, (3) Indicator Lamp, (4) Variable Thermostat Regulator, (5) Thermocouple Sensor, (6) Heating Element, and (7) Oven Heat Chamber

The heating element was installed at the base and on top of a refractory ceramic tile inside the oven to enable convective heat transfer upward into the entire chamber. The heating element was placed over the base of the heating chamber to enhance heat flow distribution. The refractory material is placed close to and below the heating element because it not only protects the bottom composite panel from direct contact but also helps minimize heat loss and reflect the heat into the oven chamber.

Placeholders were created to support the two stack trays. The steel trays had a mesh geometry that enables even temperature distribution in the oven chamber.

Oven performance. Oven performance is a measure of the general performance of the oven. Oven performance is characterized by energy input rate, preheat and energy consumption, cooking energy efficiency, production capacity, and cooking uniformity. ASTM standard F1521, which applies to both gas and electric ranges and cooktops (ASTM 2012) for cooking efficiency determination [23], was adopted. The oven cooking efficiency test was conducted by heating 6 kg (6 L) of water (specific heat (*C*) of 4,180 J/kg·K) in a 255 mm inner diameter, 127 mm height, and 2.0 mm thick aluminum stock pot, considering the oven size. The water was heated from 23 ℃ to 96 ℃ using the oven with measured heater resistance (*R*) of 40.5 Ω and operational measured power supply voltage (*V*) of 206 V, 50 Hz, and power factor of 1.0. The temperature reached 96 ℃ in 1 h 15 min. The efficiency was calculated as the change in thermal energy of the water divided by the energy consumption of the oven.

Power supply to the device: $P = \frac{V^2}{R} = \frac{206^2}{40.5} = 1047.80447$ W,

Cooking efficiency: $\eta_c = \frac{m*C*\Delta T}{P*\Delta t} = \frac{6*4180*73}{1047.80447*4500} = 0.38829202 = 38.8\%$,

where ΔT is the change in temperature and Δt is the change in time.

3. Result and Discussion

By sandwiching the glass wool insulation within the double-panel walls, heat transfer to the thermal mass outside the cavity was isolated, which necessitated the quicker attainment and retention of high temperature (i.e., up to 150 ℃) within the oven cavity using only 1.0 kW electric heating element and having a cooking efficiency of 38.8%. Figure 2(a) shows the functional, portable, robust, and esthetic electric heat oven with an overall dimension of 450 mm length × 450 mm width × 600 mm height. The top has a compartment that houses the electrical wirings with an access opening for inspection and maintenance. The front has a control panel with a temperature regulator, fuses, and an indicator lamp. The oven chamber has a sandwich door of 450 mm × 450 mm × 30 mm hinged at the bottom used for placing and removing products into and from the oven and properly sealing the chamber when closed under staple locks. At the sides are the lifting handles and at the bottom are four standing supports to clear it from the ground. Figure 2(b) shows the back of the oven with the electrical receptacle connecting to the mains.

(a)

(b)

Figure 2. (a) Frontside of the Electric Oven; (b) Backside of the Electric Oven

Figure 3 shows the interior view of the electric oven with two stacks of product carriers made of steel mesh. The mesh enables the free flow of heat to all of the parts of the chamber by convection heat transfer. The heating chamber forms a cuboid and has a width of 400 mm, a depth of 400 mm, and a height of 400 mm. At the bottom of the inner chamber is the refractory ceramic tile on top of which lies the electric heating element. The heating element is located at the bottom to enable the heated air surrounding it to move upward by natural convection, thereby saving the cost of using forced convection. The thermostatic regulator sensor is located inside the oven chamber, particularly at the back, where it detects heat and sends a signal to the regulator. The front door is the access point to the heating chamber.

Figure 4 shows the electrical wiring compartment of the oven. The wires were used to connect the instruments on the control panel to the sensor and receptacle. From the compartment box, the wires were passed through conduits to the back of the oven into the receptacle where another cable is used to connect it to the mains.

Figure 3. Interior of the Chamber of the Electric Oven

Figure 4. Electrical Wiring Compartment of the Oven

Figure 5. Control Panel of the Electric Oven

Figure 5 shows the controls of the electric oven. The dials were graduated in degrees centigrade with a maximum reading of 400 °C. It has green and red indicator lights to indicate temperature cut-in and cut-out, respectively. The thermostatic temperature regulator was installed with a sensor fitted into the heating chamber. The regulator works on the principle of a thermostat, i.e., using a bimetallic strip that functions to maintain a steady temperature. Once there is an electric power supply, when the control knob is turned from the zero position to select the desired temperature, the temperature of the device increases. As the oven reaches the desired temperature, the bimetallic strip in the thermostat expands in such a way that it loses contact, thereby breaking the circuit. As the heating elements cool, the strip contracts and makes contact again, thus switching on the electrical circuit once more. This make-and-break device regulates the temperature of the heating coil to any setpoint temperature needed at any moment by tripping off. It waits until the oven temperature goes back to normal, and contact is made again to heat up to the required temperature. It has a cut-in and cut-out temperature of 5 °C. On the panel is a large indicator lamp in between two fuse holders. The lamp indicates supply from the mains reaching the oven. The fuses were installed to safeguard against power surges, hence protecting the oven and its installations.

4. Conclusions

The oven has a heating chamber with a variable temperature regulator and two heating hangers that ensure flexibility in cooking, roasting, baking, and drying of food materials, as well as warming already cooked food. The oven that is fabricated using composite materials has some superior mechanical properties to those fabricated using some other materials, such as metal and wood. Some of these properties include lightweight, oxidation resistance (i.e., they do not corrode easily as most metals), high yield strength, ease of fabrication and maintenance, and excellent damping and insulation of heat and electricity. In this study, the appropriate material and insulation thickness were selected to reduce the heat losses considerably. A temperature regulator was installed to vary the oven temperature between the safe range, i.e., from ambient up to 150 °C. The top cover of the oven is the circuit compartment and enables easy maintenance of the oven. The cooking efficiency of the oven is 38.8%, and the prototype production cost is less than US$300. This performance is comparable to the high-cost ovens in the market, thus making the locally manufactured oven a good choice to meet the needs of developing countries and the requirements of laboratory tests, i.e., a low-pressure, moderate-temperature oven. Further research will concentrate on the heating characteristics and behavior and the effectiveness of the composite electric oven.

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