Microcontroller PIC 16F877A standard based on Solar Cooker using PV- Evacuated tubes with an extension of heat integrated energy system

Arulraj Simon Prabu[1&a*], Venkatesan Chithambaram [2], Maria Anto Bennet [3], Sengottaiyan Shanmugan [4*] Catalin Iulian Pruncu [5&b], Luciano Lamberti [6] Ammar Hamed Elsheikh[7], Hitesh Panchal [8] Balasubramani Janarthanan[9]

[1]Department of Electronics and Communication Engineering, Sriram Engineering College, Perumalpattu, Chennai, Tamil Nadu, India – 602024.

[a] Department of Physics, Dhanalakshmi College of Engineering, Tambaram, Chennai, Tamil Nadu, India-601301.

[2] PERI Institute of Technology, No.1, Near, West Street, Tambaram, Mannivakkam, Tamil Nadu 600048, India.

[3] Department of Electronics and Communication Engineering, Vel Tech Rangarajan Dr. Sakunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamil Nadu, India – 600 062.

[4] Research Centre for Solar Energy, Department of Physics, Koneru Lakshmaiah Education Foundation, Green Fields, Guntur District, Vaddeswaram, Andhra Pradesh 522502, India.

[5]Design, Manufacturing & Engineering Management, University of Strathclyde, Glasgow, G1 1XJ, UK.

[b] Department of Mechanical Engineering, Imperial College London, Exhibition Rd., London, UK

[6] Dipartimento di Meccanica, Matematica e Management, Politecnico di Bari, Bari, Italy

[7] Department of Production Engineering and Mechanical Design, Tanta University, Tanta 31527, Egypt.

[8] Mechanical Engineering Department, Government Engineering College Patan, Gujarat, India- 384265.

[9] Department of Physics, Karpagam Academy of Higher Education, Eachanari, Coimbatore, Tamil Nadu, India - 641021.

Emails ID : [1]simonprabu07@gmail.com, [3]chithambaramv@gmail.com, [3]bennetmab@gmail.com, [4]s.shanmugam1982@gmail.com, [5]Catalin.pruncu@starth.ac.uk, [6]luciano.lamberti@poliba.it [7]ammar_elsheikh@f-eng.tanta.edu.eg, [8]engineerhitesh2000@gmail.com, [9]**bjanarthanan2010@gmail.com**

* **Corresponding author, *E-mail address:* [1] simonprabu07@gmail.com and** s.shanmugam1982@gmail.com.

Abstract

The unavailability of sunlight during nighttime and cloudy weather condition has limited the usage of solar cookers throughout the day. This study will attempt to engineer a solar cooker with PV (Photovoltaic panel), evacuated tubes with CPC reflectors, battery and charge controller using the microcontroller PIC 16F877A. A mathematical model is developed to predict the electrical power (E_p) required during cloudy weather condition and nighttime as well as the temperatures occurring at different parts of the cooker. The proposed model is validated against experimental observations gathered for one of the typical working days of the system. The cooker is tested for various cooking

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loads to find the cooking time and it is proven that the proposed cooker can be utilized over 24/7 without interruption.

Keywords: Solar cooker, charge controller, evacuated tubes, PV panel

Introduction

Solar cookers have immense intensity to make food for smaller and larger communities, which include hospitals, colleges, industries etc. Commercial Box-type solar cookers are limited to use due to their non-functionality during cloudy weather and nighttime. These limitations have been slowly overcome making efforts to introduce electrical backup by solar panel with heating coils to supply auxiliary heat during daytime and storage of electrical power in the battery whose charge can be extracted to supply for the heating coil during nighttime and cloudy weather for cooking. Researchers carried out experimental work with their proposed cookers with electrical backup and heating coil to supply heat energy for cooking. Results of the study have been documented for the welfare of the researchers in the respective field. The solar cooker technology is clean, efficient with a wide range of possible applications in eliminating pollution Thamizharasu *et al*., (2020). Since the amount of solar box cookers is fixed, many scientists are trying to develop efficient solar cooking systems Shanmugan *et al.,* (2020). The exploitation of technological developments Palanikumar *et al.,* (2021), including numerical simulation Bhavani *et al.,* (2019), is an important approach that precedes experimental work to reduce the waste of time, effort by Bhavani *et al*., (2021) and money Palanikumar *et al*., (2019). Since solar cooking gathered a lot of attention, a brief survey of previous studies on this subject is now presented Bhavani *et al.,* (2018). Palanikumar *et al*., (2021) studied a stepped solar cooker using a bar plate with SiO_2/TiO_2 nanoparticles at different concentrations equal to 10 and 15%. The experimental results confirmed that solar cooker efficiency reaches 37.69% for a 10% concentration of SiO_2/TiO_2 nanoparticles and 49.21% for a 15% concentration. Rakesh Kumar *et al.* (2001) have designed a community type solar cooker using 5 evacuated tube solar collectors. Thermal analysis has been done and simulation results confirmed the possibility of cooking of several batches. A prototype solar cooker incorporated with phase change material unit has been fabricated by Sharma *et al.* (2005) to utilize in late evening and nighttime. It has been inferred that due to PCM material erythritol, cooker can be used in the evening.

Pinar Mert Cuce (2018) compared box-type solar cookers with and without Bayburt stone as sensible heat storage material, which has low density and high specific heat. It is observed that adopting the Bayburt stone in the cooker enhanced the thermal performance of solar cooker compared to cooker without the stone. Saxena and Agarwal (2018) designed a hybrid solar cooker with 200W halogen lamp and trapezoidal air duct and 450 hollow copper balls. Results confirmed the efficient performance of the proposed cooker with forced convection in all climatic conditions.

Mohammad Hosseinzadeh *et al.* (2020) fabricated portable evacuated tube solar cooker and analytically studied it using Taguchi analysis. It was found that the maximum operative parameters are solar radiation, absolute pressure of vacuum tubes. Arunchala and Kundapur (2020) presented a thorough review of solar cookers with and without reflectors, panels, funnels etc. highlighting the findings of the various studies. Omara *et al.* (2020) reviewed usage of different phase change materials in solar cookers: they highlighted the results obtained by the researchers and mentioned the optimal quantity of PCM to be used. Masum Ahamed *et al.* (2020) studied the performance on a solar cooker using parabolic reflectors. Results demonstrated the maximum reflection of solar radiation by mylar tape reflector.

Devan *et al.* (2020) reviewed solar cookers with tracking mechanism. The review emphasized the tracking system using microcontrollers, manual tracking and thermal and parabolic systems. Mawire *et al.* (2020) used two cooking pots with sunflower oil sensible heat storage fluid and erythritol phase change material for cooking during on/off sunlight, which is an experimental that sunflower grease cooking vessel has better performance with lesser heat utilization efficiency. Coccia *et al.* (2020) tested a solar cooker provided with dual penned container filled by phase change material of 2.5kg of erythritol. Experimental results proved the extension of load cooling time by 351.16%. Thirugnanam *et al.* (2020) obtainable comprehensive evaluation on phase change materials used a solar cooker and mentioned the quality requirements of PCM is used the designs. Bhave and Kale (2020) used a phase change material solar salt and proved the possibility of frying and cooking in the shade inside the kitchen. Nokhosteen and Sobhansarbandi (2020) adopted the Resistance Network (RN) model to predict the performance on solar collectors using heat pipe evacuated tube. Results of a model was in excellent agreement with the experimental work with a minimum error of 10%.

Very recently, Hosseinzadeh *et al.* (2021a) designed and tested a solar cooking unit incorporated with solar collector and used thermal oil based nanofluids. It is observed that SiC-oil nanofluid dominates other nanofluids (TiO_2-oil and SiO_2-oil) on the overall energy efficiency of the system. Hossienzadeh *et al.* (2021b) have studied a solar cooker as using multi-walled carbon nanotube oil nanofluid in an indirect solar cooker with collector and cooking unit. The study revealed the enhancement of the model.

Current work, as a solar cooker with PV, evacuated tubes, charge controller PIC 16F877A, Nichrome heating coil and battery have been analyzed and studied an analytical model. The goal is to predict the concert with a design. Mathematical expression derived an electrical power (E_p) based on the heat transfer process mechanisms are designed an evacuated tube collector, Nichrome coil wounded cooking vessels, charge controller, solar panel and a battery. The cooker is integrated with thermal and photovoltaic power to make it possible cooking over 24/7 without interruption.

The article is structured in place of tracks on solar cooker and designated the next segment. Third section as a paper presents the thermal simulation model established new design performance. Last two sections current the consequences of the simulation model showing their agreement with experimental measurements. The main findings of the study are summarized in the concluding section.

Design of the cooker

The compatible solar cooker developed in this study has four components:

- Evacuated tubes with high vacuum ($P < 5 \times 10^{-3}$mbar) enclosed in rectangular wooden box with parabolic trough reflectors;
- Solar photovoltaic panel (2 x 100W);
- 12 V 75AH Battery;
- Stove with two vessels for cooking.

A compatible solar cooker with photovoltaic panel and evacuated tubes (Solar Chulha) has been designed and fabricated. Evacuated tubes with high vacuum ($P<5 \times 10^{-3}$Pa) have been used in the proposed cooker and the system is used for producing hot water at about 75°C for cooking. Parabolic trough reflectors are designed and the evacuated tubes have been fixed on the focal line of the trough near obtain determined a solar energy. A copper tubes carrying heat transfer fluid (water) is made to run through an evacuated tubes near excerpt temperature received by a tubes performance is higher. Photovoltaic panel of power output 200W has been used to charge 12V 75 AH battery. The charge from the battery is used to heat the heating filament (Nichrome) covering the cooking vessel. Hot water from the evacuated tubes is further heated up to the boiling point and food is cooked easily. Furthermore, DC electrical power from the panel is stored in the battery during daytime and can be used during night. Figures 1 through 3 show the photograph of the solar cooker and its different components.

Thermal Model of the Solar Cooker

Five evacuated tubes are mounted on the focal line of the CPC reflector and are enclosed in a rectangular box made of plywood. Glass wool insulators are introduced in the gap between the CPC reflectors and glass cover of thickness 3mm has been used to cover the rectangular box. The evacuated tubes have length of about 490 mm while the inner and outer diameters of each tube are 33mm and 44mm, respectively. Copper tube of diameter 3mm are made to run through the evacuated tubes continuously from the first evacuated tube to last evacuated tubes, which are arranged in a sequence inside the rectangular box. Cooking liquid allowed near movement complete a copper pipes through an inlet first evacuated tube using a valve to control the movement amount on cooking liquid.

Collector performance determined through finding the total energy absorbed and utilized by the collector and the first law of thermodynamics is used an energy balance equation as

$$\sum E_{ab} = E_{ut} \tag{1}$$

where E_{ab} is the energy absorbed or transferred to the collector and E_{ut} is the energy an increase the temperature levels (fluid acts), useful energy utilized by the collector is:

$$Q_u = mC_{pw}(T_{out} - T_{in}) \tag{2}$$

where

$m - Mass\ flow\ rate\ of\ working\ fluid\ water\ (kg)$

$C_{pw} -\ Specific\ heat\ capacity\ of\ water\ \left(\frac{J}{kgK}\right)$

$T_{out} -\ Output\ temperature\ of\ water\ (K)$

$T_{in} -\ Inlet\ water\ temperature\ (K)$

The energy effectively collected by the system is:

$$Q_{col} = A_{col}F_R \cdot \left[I_t \cdot (\tau\alpha)_e - U_L\left(T_{aref} - T_a\right)\right] \tag{3}$$

where:

$Q_{col} - \mathit{Total\ energy\ collected\ by\ the\ collector}$;

$A_{col} - \mathit{Area\ of\ the\ collector}\ (m^2)$;

$F_R - \mathit{Collector\ efficiency\ factor}$;

$I_t - \mathit{Solar\ radiation}$ (W/m^2);

$(\tau\alpha)_e - \mathit{Effective\ transmittance\ absorptance\ product}$;

$U_L - \mathit{Total\ heat\ loss\ efficiency}$ (W/mK);

$T_{aref} - \mathit{Average\ temperature\ of\ the\ refrigerant}\ (K)$;

$T_a - \mathit{Ambient\ Temperature}\ (K)$.

From the energy collected, it is possible to calculate the efficiency of the solar device as:

$$\eta_e = \frac{Q_{col}}{A_{col}\, I_t} \quad (4)$$

Hence, efficiency can be expressed as:

$$\eta_e = F_R \cdot (\tau\alpha)_e - \frac{F_R U_L (T_{aref} - T_a)}{I_t} \quad (5)$$

Fig. 4 shows a schematic representation of the displaced pipe with a copper pipe running it. Copper tube is shaped as a u-tube and inserted in the displaced pipe. Copper tube an outlet from the first displaced pipe is an inlet to a second displaced pipe and so on. Solar energy entered complete a transfer materials are absorbed onto the evacuated tubes. Heat energy is connected to the copper tube inside the fluid water is moved to the working process. A cooking fluid (i.e. working fluid water flowing out through the outlet of the fifth evacuated tube) reaches a maximum temperature. The flow rate of water through the copper tube is maintained in such a way to absorb enough thermal energy from the copper throughout its passage through the tube till it reaches the outlet. The design an outer glass cover is used an energy balance equation (i.e. the covering glass for the evacuated tube collector) as follows.

<u>Covering glass cover</u>

$$I_t A_g \propto_g + h_{cogg}(T_{eog} - T_{og})A_g + h_{rogg}(T_{eog} - T_{og})A_g = h_{coga}(T_{og} - T_a)A_g + h_{roga}(T_{og} - T_a)A_g \quad (6)$$

Outer glass tube of the evacuated tube

$$\tau_g \alpha_{eg} I_t A_{eog} + h_{cigog}(T_{eig} - T_{eog}) A_{eog} + h_{rigog}(T_{eig} - T_{eog}) A_{eog} = h_{coga}(T_{eog} - T_a) A_{eog} + h_{roga}(T_{eog} - T_a) A_{eog} \quad (7)$$

Inner glass tube of the evacuated tube

$$h_{cogig}(T_{eog} - T_{eig}) A_{eig} + h_{rogig}(T_{eog} - T_{eig}) A_{eig} = h_{cigct}(T_{eig} - T_c) A_c + h_{cigct}(T_{eig} - T_c) A_c \quad (8)$$

Copper tube

$$h_{cigct}(T_{eig} - T_c) A_c + h_{cigct}(T_{eig} - T_c) A_c = h_{cctw}(T_{ct} - T_w) + h_{rctw}(T_{ct} - T_w) \quad (9)$$

Water

$$m_w C_w \frac{dT_w}{dt} + h_{cctw}(T_{ct} - T_w) + h_{rctw}(T_{ct} - T_w) = 0 \quad (10)$$

Eqs. (6) through (9) have been solved for the temperature of the outer glass cover (T_{og}), for T_{eog} is outer glass tube of the evacuated tube, as T_{eig} is inner glass tube of the evacuated tube, T_c is copper tube. The evacuated tube water is used in a solar collector that solution of the Eq. (10) is obtained and it gives the outlet temperature (T_{out}).

Outlet cooking fluid temperature from the evacuated tube collectors reaches a maximum of 80°C and is hence introduced into the cooking vessel, which is fitted in a wooden enclosure. The sides and bottom of the cooking vessels are well insulated using glass wool insulator with thermal conductivity of 0.0038 W/mK. The cooking vessel is made of aluminum and provided with an aluminum lid. Nichrome coil is wounded on the sides of the cooking vessel to provide the electrical backup.

The hot cooking fluid output the displaced pipe accumulator is introduced in the cooking vessel to cook food. Hot water temperature is T_{out} from an evacuated pipe collector and used for cooking fluid the energy again equations base of a cooking vessel can be written as:

$$P_e A_b \times t + T_{out} A_b SM = h_{bs} A_b (T_b - T_a) \quad (11)$$

Similarly, the energy balance for the sides of the cooking vessel is stated as:

$$P_e A_s \times t + T_{out} A_s SM = h_{bs} A_s (T_s - T_a) \tag{12}$$

The outlet water from the evacuated tube into the cooking vessel absorbs the thermal energy supplied by the Nichrome heating coil surrounding the base and sides of the cooking vessel. The cooking fluid temperature increases due to the absorption of energy from electrical back up and thus food items in the vessel can be cooked. Therefore, the temperature of cooking fluid (T_{cf}) can be balanced with respect to that of the absorbed energy using the relationship:

$$\frac{dT_{cf}}{dt} + aT_{cf} = f(t) \tag{13}$$

where a and $f(t)$ are constants that can be determined from the equations relative to temperature components of the evacuated tube collector, Nichrome heating coil and cooking vessel respectively.

At $t=0$, $T_{cr}=T_{cf0}$ and due to the initial condition from Eq. (13). We are writing as

$$T_{cf} = \frac{f(t)}{a}(1 - e^{-\propto t}) + T_{cf0} e^{-\propto t} \tag{14}$$

where α is a constant of a cooker with a different heat transfer coefficients by a system

As an electrical power is supplied due to the conversion of absorbed solar energy by the panel of power 200W, it is indispensable to consider the incoming solar energy by the aperture of the panel in the respective interval of time. It is also considered that the charge controller is capable of charging the battery and supplying electrical power to the Nichrome heating coil without any interruption. Therefore, the input energy for the cooker with electrical back up can be written as:

$$E_i = I_t A_p \tag{15}$$

The energy output of the cooker is given by:

$$E_o = \frac{mC_f(T_{cf} - T_{out})}{t} \tag{16}$$

From the two equations (15) and (16), the thermal energy efficiency by a system is

$$\eta = \frac{E_o}{E_i} \tag{17}$$

Therefore,

$$\eta = \frac{mC_f(T_{cf} - T_{out})}{I_t A_p t} \tag{18}$$

Results and Discussion

The evacuated tube collector was tested separately with a temperature component, which is measured along sun rays, ambient temperature intermittently using solar radiation monitor. The measured data (solar radiation and ambient temperature) relative to one of the typical experimental days was used for calculations as shown in Fig. 5. The variation with a glass cover temperature an evacuated tube solar collector has been respected to the time allows one liter water, which is allowed to flow over the copper tube as shown in Fig. 6. The glass cover temperature influences the temperature of 62°C in 50 minutes as the glass cover covering the enclosure of the evacuated tube collector has larger aperture to receive the sun energy.

Energy balance equation of a soluction from Eq. (6) is obtained a glass cover temperature for the theoretical value also determined. It is showed from Fig. 6 that theoretical and experimental values have practically the same trend throughout time. Therefore, the analytical solution for the glass cover can be used for the simulation model in any other similar location having same climatic conditions.

Fig. 7 compares the theoretical and experimental values for the temperature of an outer glass tube with an evacuated tube collector. Numerical results created an analytical solution an outer glass tube energy balance equation (Eq. (7)) clearly show that the computed values follow experimental values all the time without much deviation. An outer glass with an evacuated tube is received a thermal energy from trapped and the remaining amount of energy is sent to the path of the temperature component of the system.

An inner glass tube with an evacuated tube in various temperatures were calculated by solving Eq. (8) and the numerical values were plotted along with the experimental observations in Fig. 8. Heat energy reaching an internal glass pipe is trapped due to evacuation, which is an inner glass tube temperature as gradually increases with beginning and abruptly increased due to evacuation. It appears from the figure that theoretical predictions and experimental observations agree very well throughout the working time due to the exact evaluation of the component created an energy balance equation.

A copper tube (evacuated tube) has been inserted into the U-shaped pipe an output is first provided the input of the second and so on. The copper tube receives the heat energy from an inner glass tube, which is trapped inside the tube energy without much loss.

A copper tube is showed in Fig. 9 with a variation's temperature by deference near period; analytical results created solution an energy balance equation was obtained from Eq. (9). The thermal energy absorbs by the copper tube with flowing water throughout, its path. It reaches the outlet of the displaced pipe collector temperature by a fluid becomes maximum.

The water temperature increases in every step (i.e. every evacuated tube) and water outlet from the last evacuated tube reaches the maximum temperature. It was solved energy equations determining a water temperature with an outlet to a collector, when the results were evaluated. Fig. 10 is valued an experimental data and analytical results are plotted with respect to time. An outlet of evacuated tube collector with temperature is reached the maximum of 96°C.

Furthermore, the theoretical outcomes have been closed the contract an investigational explanations. It is possible to get low pressurized steam if the flow rate of water through the copper pipes were adjusted an intermittent steam may be produced with optimum movement amount of an aquatic.

Discussed above results an indicate simulation model developed in this study predicted the temperature components of the system with very small errors. Therefore, for the evacuated tube collector, the model can be used to simulate the collector for any location and it may be possible to optimize design parameters for community-based installments.

The outlet water was introduced into the cooking vessel seeing that the water itself has to move through a certain distance in open environment and flow into the cooking vessel. Hence, an evacuated tube collector water temperature through an outlet is decreases by some extent before it reaches the cooking vessel. During its path, some energy was lost to the surroundings and water temperature an inlet of a cooking vessel decreased to 74°C. Therefore, after the introduction of hot water into the cooking vessel, auxiliary heat energy is supplied by electrical backup.

The base and sides of the cooking vessel receive heat energy from electrical backup as well as via convection of heat energy from the cooking fluid to the base and sides. Therefore, it is indispensable to find the analytical results for the temperature of the base and side of the vessel based on energy process. An analytical solution for the two components was obtained and it is plotted along with experimental observations as shown in Fig. 11 and Fig. 12 a directive that confirm to the model. It is variations temperature in base, for side cooking vessel with respect to the working hours. The theoretical results were moral contract by an experimental observations.

Therefore, thermal simulation model developed in energy process of a temperature component gives precise results and can be used for portraying the system behavior.

An evacuated tube collector is allowed flow hot water into cooking vessel, thus supplying the cookery liquid. A cooking fluid temperature at the cooking vessel is nearly 74°C and auxiliary heat is supplied to the cooking fluid by the Nichrome coil wounded over the sides in cooking pot. A fluid of a cooking temperature raises, food is cooked. An analytical solution for the cooking fluid temperature is used to calculate a cooking fluid temperature any instant of period with Eq. (14). An experimental observations and the theoretical calculations done for cooking fluid temperature are associated with a Fig. 13. It can be seen that theoretical and experimental results are as expected and agree very well with small deviations. This is due to the intermittent nature of cooking fluid temperature an incorporated to a food item.

The thermal model developed for determining temperature elements of the cooker is moral arrangement by an investigational consequence. Cooking fluid temperature is used to find the energy output of the proposed system with electrical backup. Energy output with electrical backup was calculated then which is experimental follow of water fever from an evacuated pipe collector was 75°C and it is fed into the cooking vessel. The temperature was further increased to 96°C by utilizing the electrical backup for a time period of 15 minutes. The temperature of the cooking fluid should be sustained for 45 minutes to cook 1kg of rice. The electrical backup required to sustain the temperature of the cooking fluid was found to be 0.15 unit of electricity with power of 160 W. Energy input to the cooker can be calculated using Eq. (15) and the efficiency of the cooker is estimated with the energy output and energy input using Eq. (18).

The resulting efficiency of the proposed system with a load of 1kg of food stuff was found to be 36.52%. This was achieved by using the electrical backup supplied by the Nichrome heating coil. The system was used to cook different food stuff and is tabulated in Table 1.

Conclusion

The paper described a novel solar cooker design including photovoltaic panels, evacuated tubes with CPC reflectors, battery and charge controller using the microcontroller PIC 16F877A. An analytical model was established with a simulating the thermal performance on the cooker, it is validated against experimental measurements.

The subsequent inferences have been strained from this study:

(i) Figure of Merit (F_1) and Figure of Merit (F_2) for the cooker have been found as 0.1197 and 0.4018, which met the value of Bureau of Indian Standard.

(ii) As the cooking vessel is well thermally insulated using glass wool of thermal conductivity 0.0038 W/mK, the temperature attained using the electrical backup can be maintained for a time long enough to cook food.

(iii) The water output temperature an evacuated tube is reached a maximum of 75 to 80°C within a short interval of time with optimum movement amount to the inlet an evacuated pipe.

(iv) Validation of the thermal simulation model demonstrated the usability of the model for optimizing design parameters. Furthermore, the model can be utilized for large scale installations.

(v) The thermal efficiency of the cooker is 36.52% and the cooker can be used over the 24 hrs cycle as it is provided with a battery to store the charge.

(vi) The cooker can be used for cooking as well as frying food stuff as it is provided with electrical back up of 160W.

(vii) The cooker is affordable to a common man as the cost of the cooker is INR 10,500/- only.

Nomenclature

I_t - Intensity of solar radiation (W/m^2)

τ_g - Glass cover transmittance

α_{eg} - Absorptivity of the evacuated glass tube

A_{eog} - Outer and evacuated glass tube areas (m^2)

A_g - Total glass cover areas (m^2)

α_g - Glass cover absorptivity

A_c - Copper tube areas (m^2)

h_{cogig} - Convective heat transfer coefficient from outer - inner glass tube from an evacuated tube (W/mK)

h_{rogig} - Radiative heat transfer coefficient from outer - inner glass tube from an evacuated tube (W/mK)

T_{eog} - Outer glass tube an evacuated tube temperature (K)

T_{eig} - Inner glass tube an evacuated tube temperature (K)

A_{eig} - Inner glass tube an evacuated tube area (m^2)

h_{cigct} - Convective heat transfer coefficient from inner glass - evacuated to copper tube (W/mK)

h_{rigct} - Radiative heat transfer coefficient from inner glass - evacuated to copper tube (W/mK)

h_{cogg} - Convective heat transfer coefficient from outer glass cover to outer glass tube of the evacuated tube (W/mK)

h_{rogg} - Radiative heat transfer coefficient from outer glass cover to outer glass tube of the evacuated tube (W/mK)

h_{coga} - Convective heat transfer coefficient from outer glass cover to the ambient (W/mK)

h_{roga} - Radiative heat transfer coefficient from outer glass cover to the ambient (W/mK)

h_{cigog} - Convective heat transfer coefficient from inner to outer glass tube of the evacuated glass tube

h_{rigog} - Radiative heat transfer coefficient from inner to outer glass tube of the evacuated glass tube

h_{cctw} - Convective heat transfer coefficient from copper tube to water (W/mK)

h_{rctw}- Radiative heat transfer coefficient from copper tube to water (W/mK)

T_w - Water inside the copper tube temperature (K)

T_{ct} - Copper tube temperature (K)

E_i - Energy input cooker (J/m^2)

A_p - Aperture area solar panel (m^2)

P_e - Electrical power supplied through Nichrome coil to the base (W)

A_b - Cooking vessel base areas (m^2)

A_s - Cooking vessel side wall areas (m^2)

t - Time interval (Seconds)

T_{out} - Outlet temperature from evacuated tube collector

S - Specific heat capacity of water (J/kgK)

M - Mass of the vessel (kg)

h_{bs} - Convective heat coefficient from vessel base surroundings (W/mK)

T_b - Cooking base vessel temperature (K)

T_a - Vessel base near temperature (K)

T_s - Cooking side vessel temperature (K)

T_{cf} - Temperature with cooking fluid (K)

m - Cooking fluid mass (kg)

C_f - Cooking fluid with specific heat capacity (J/kgK)

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Conflict of Interest

There is no conflict of interest among the authors.

Author Contributions

Mr. Arulraj Simon Prabu

Synthesis of Experimental work design and characterization of Solar cooker

Dr Venkatesan Chithambaram

Analysis of results

Dr Maria Anto Bennet

Data validation, Editing of the manuscript

Dr. Sengottaiyan Shanmugan

Analysis of results, writing the manuscript, reviewing and editing the paper

Dr. Catalin Iulian Pruncu

An editing the paper

Dr. Luciano Lamberti

Data validation, Editing of the manuscript

Dr. Ammar Hamed Elsheikh

Data validation, Editing of the manuscript

Dr. Hitesh Panchal

Data validation, Editing of the manuscript

Dr. Balasubrimani Janarthanan

Data validation, Editing of the manuscript

Availability of Data and Material

The designed solar cooker and data of results of characterization are available.

Compliance with ethical standard

The research work is ethically complied.

Consent to participate

All the authors give their consent to having participated in the current work.

Consent for publication

All the authors give their consent for publication of this work.

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Figures

Figure 1

Photograph of Cooking vessel with Nichrome heating coil and evacuated tube collector.

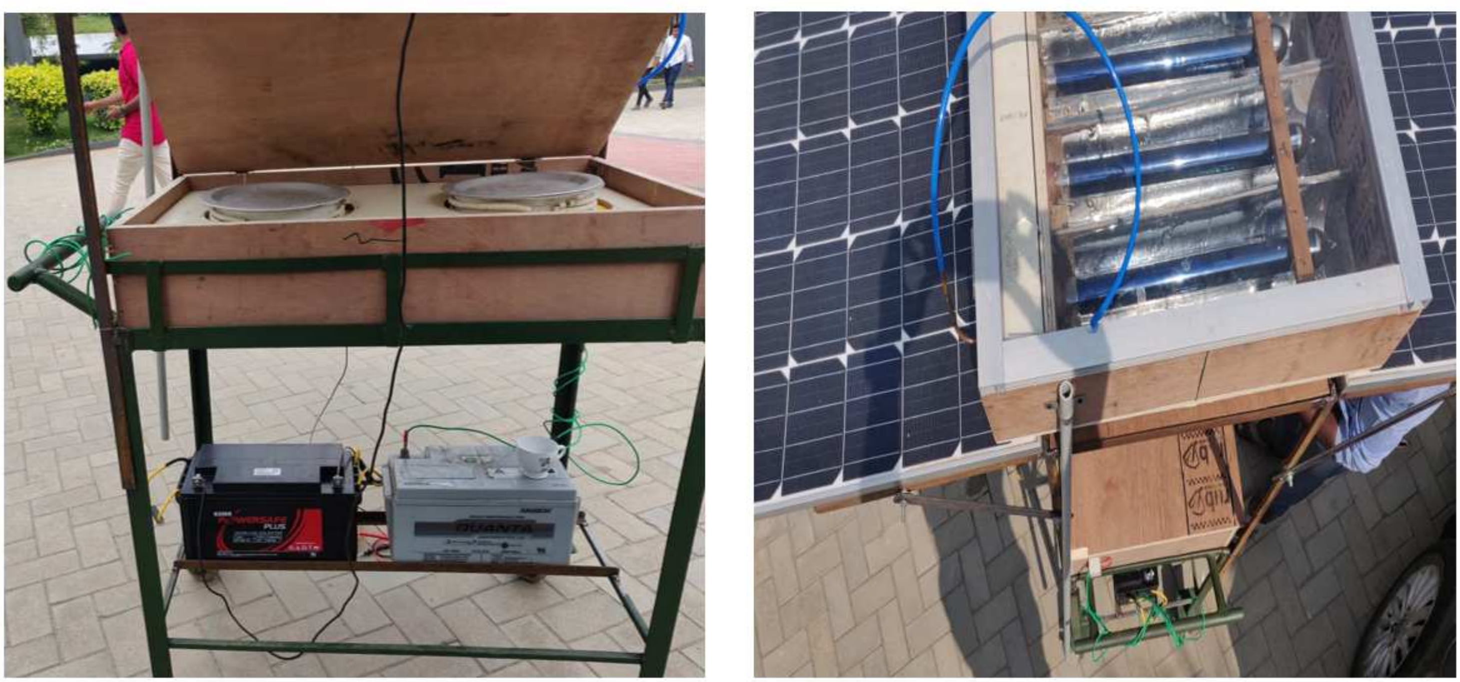

Figure 2

Photograph of the solar panel with battery and charge controller.

Figure 3

Photograph of the food cooked using solar cooker.

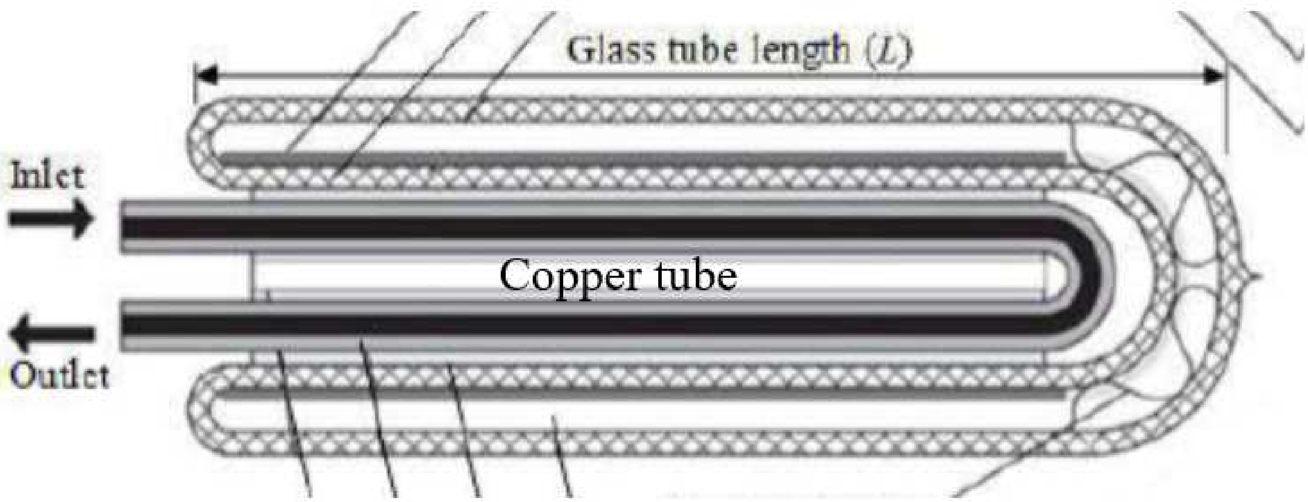

Figure 4

Schematic diagram of the evacuated tube into which is inserted the u-type copper tube.

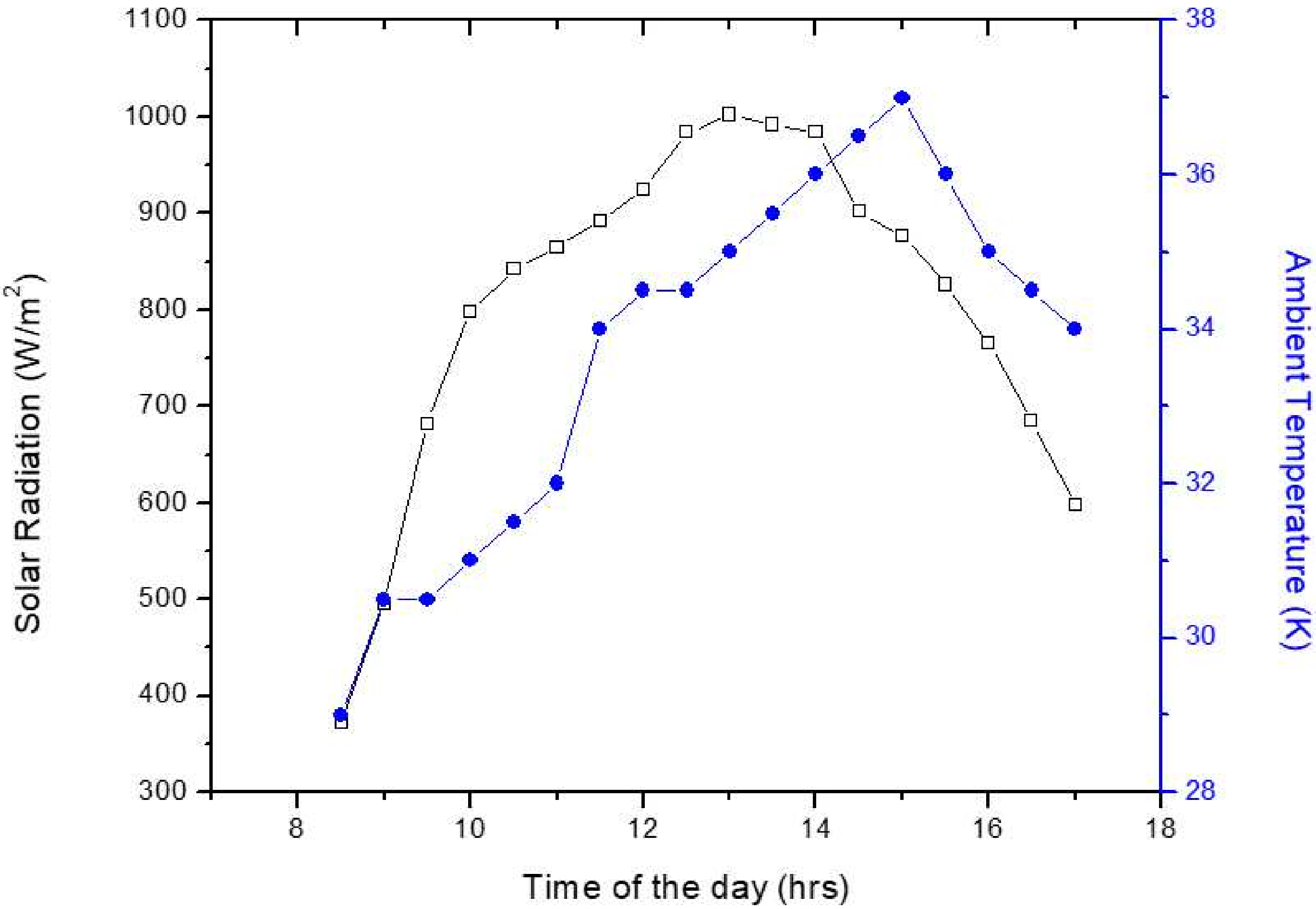

Figure 5

Solar radiation & ambient temperature recorded over a typical working day.

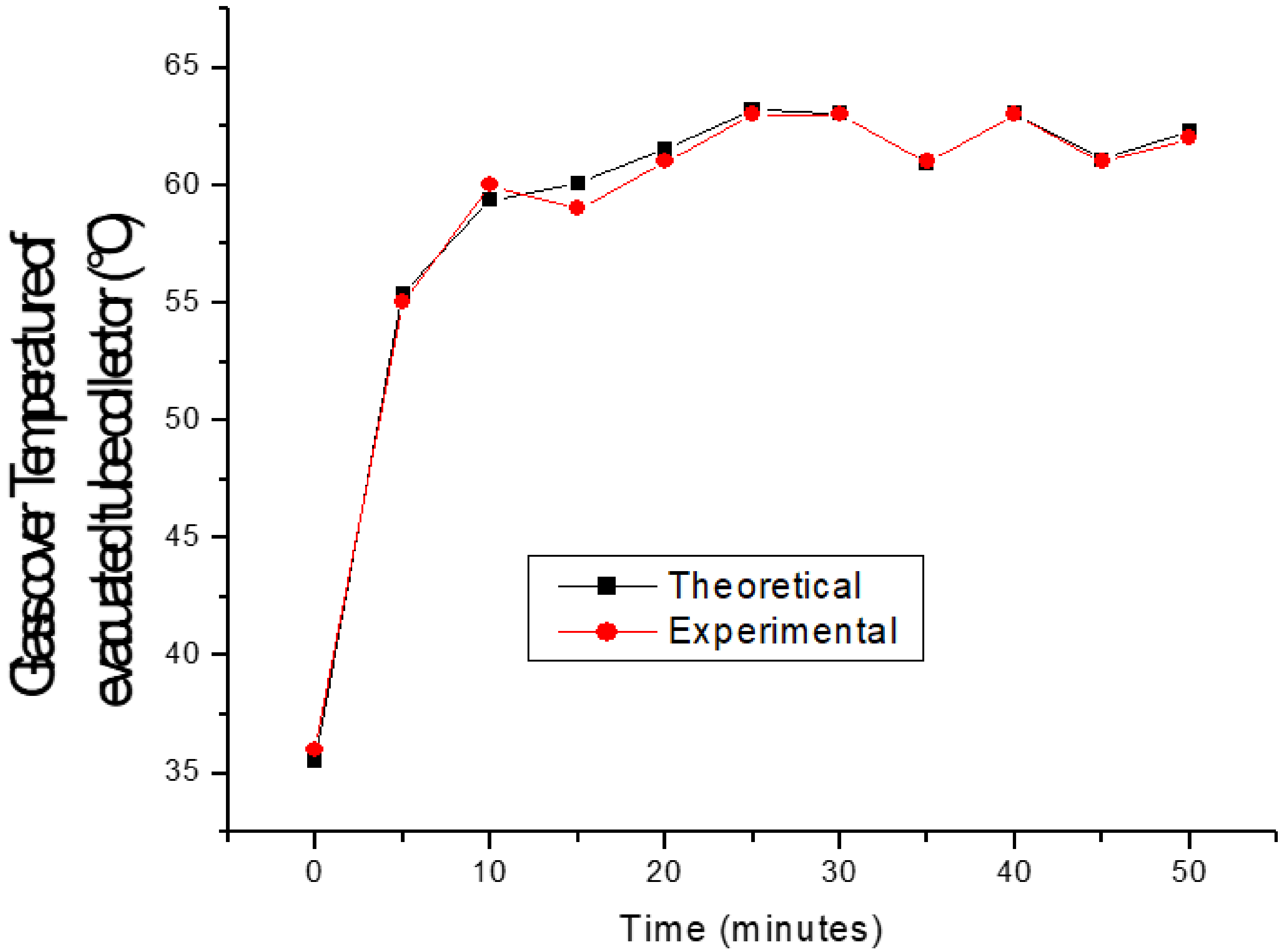

Figure 6

Variation of temperature of glass cover of evacuated tube collector with respect to time.

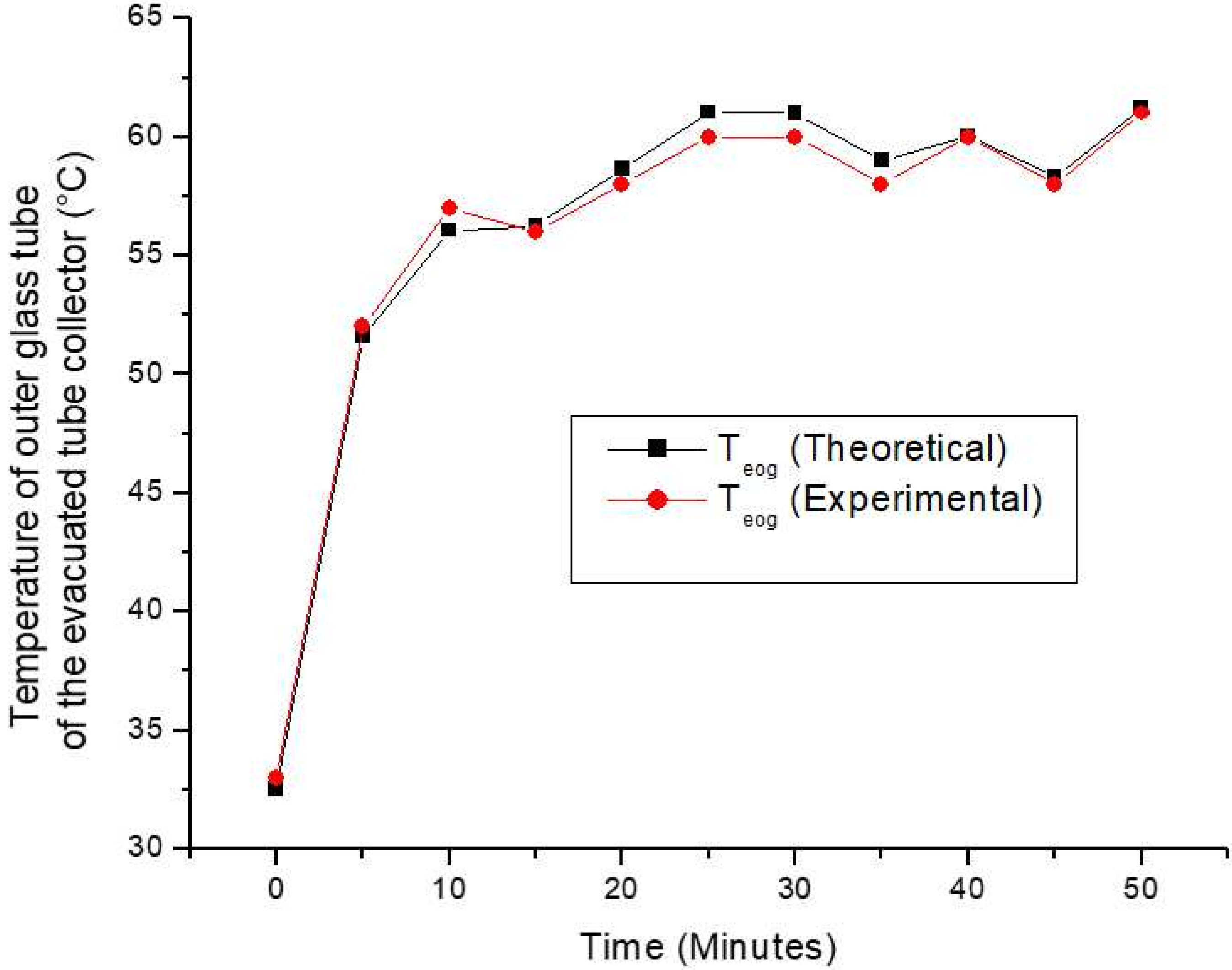

Figure 7

Experimental and theoretical temperature variations for the outer glass tube of the evacuated tube collector.

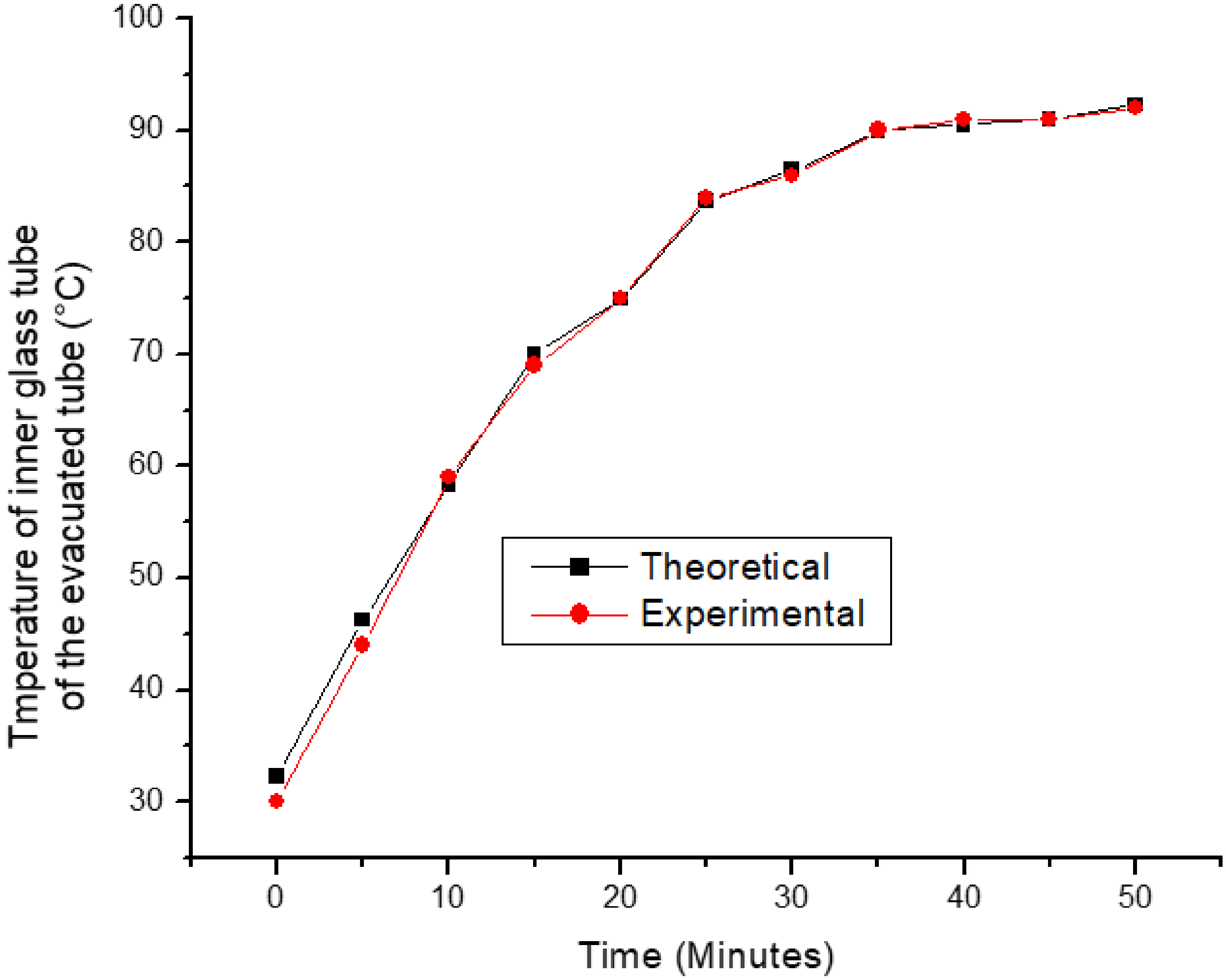

Figure 8

Temperature variations (experimental and theoretical) of the inner glass tube of the evacuated tube with respect to time.

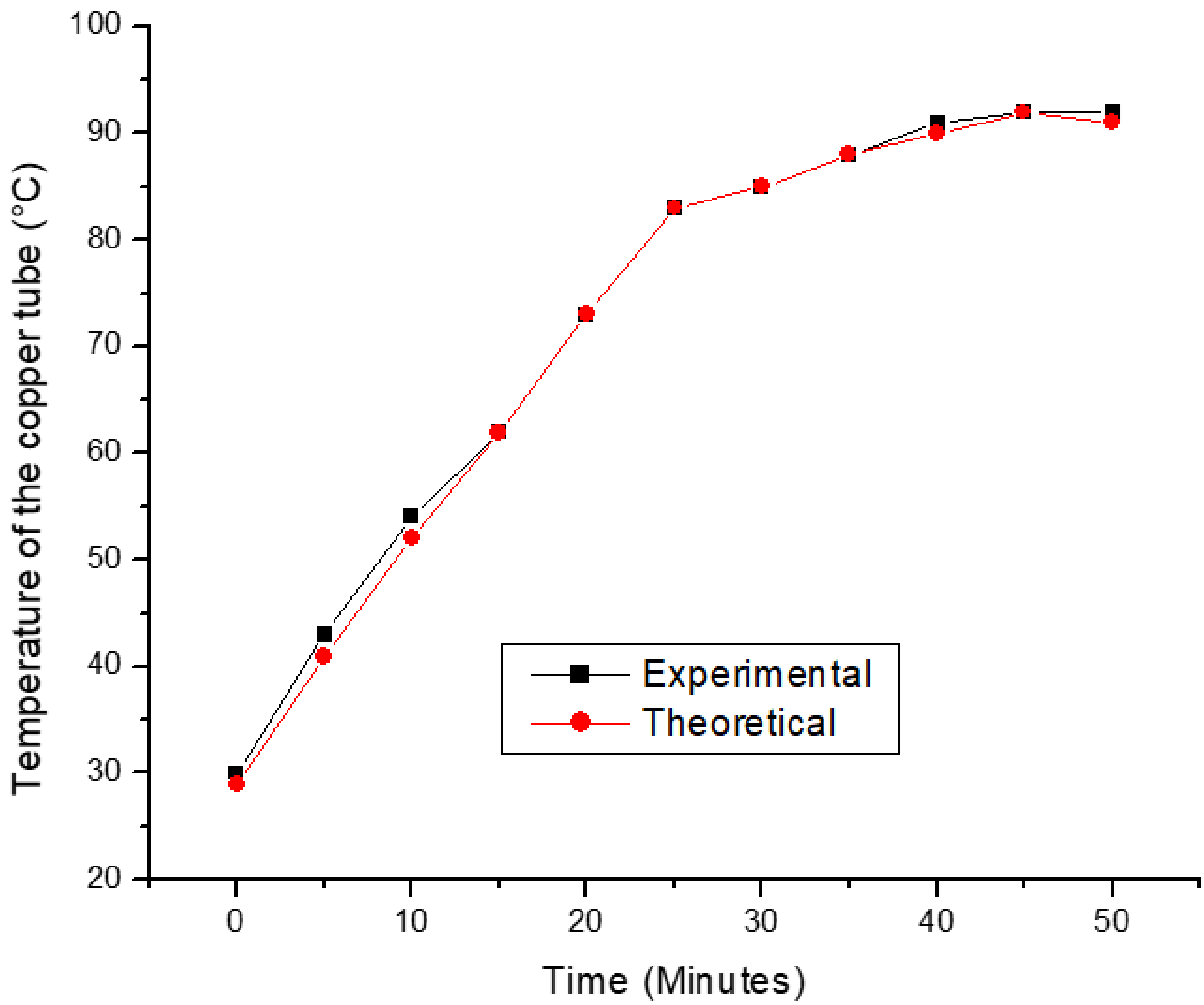

Figure 9

Experimental and theoretical temperature values for the copper tube with respect to time.

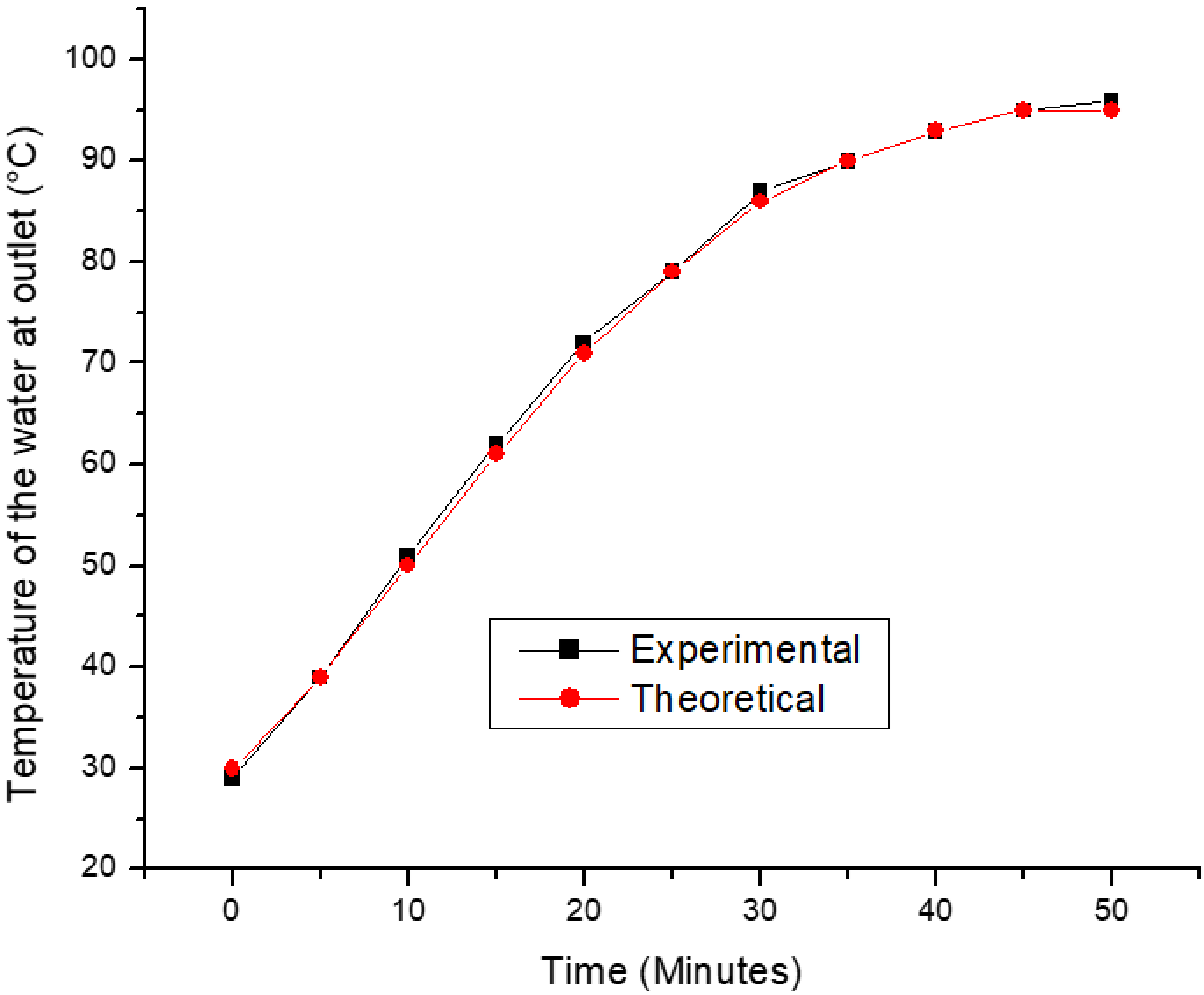

Figure 10

Temperature variations (experimental and theoretical) of water at the outlet of the evacuated tube collector.

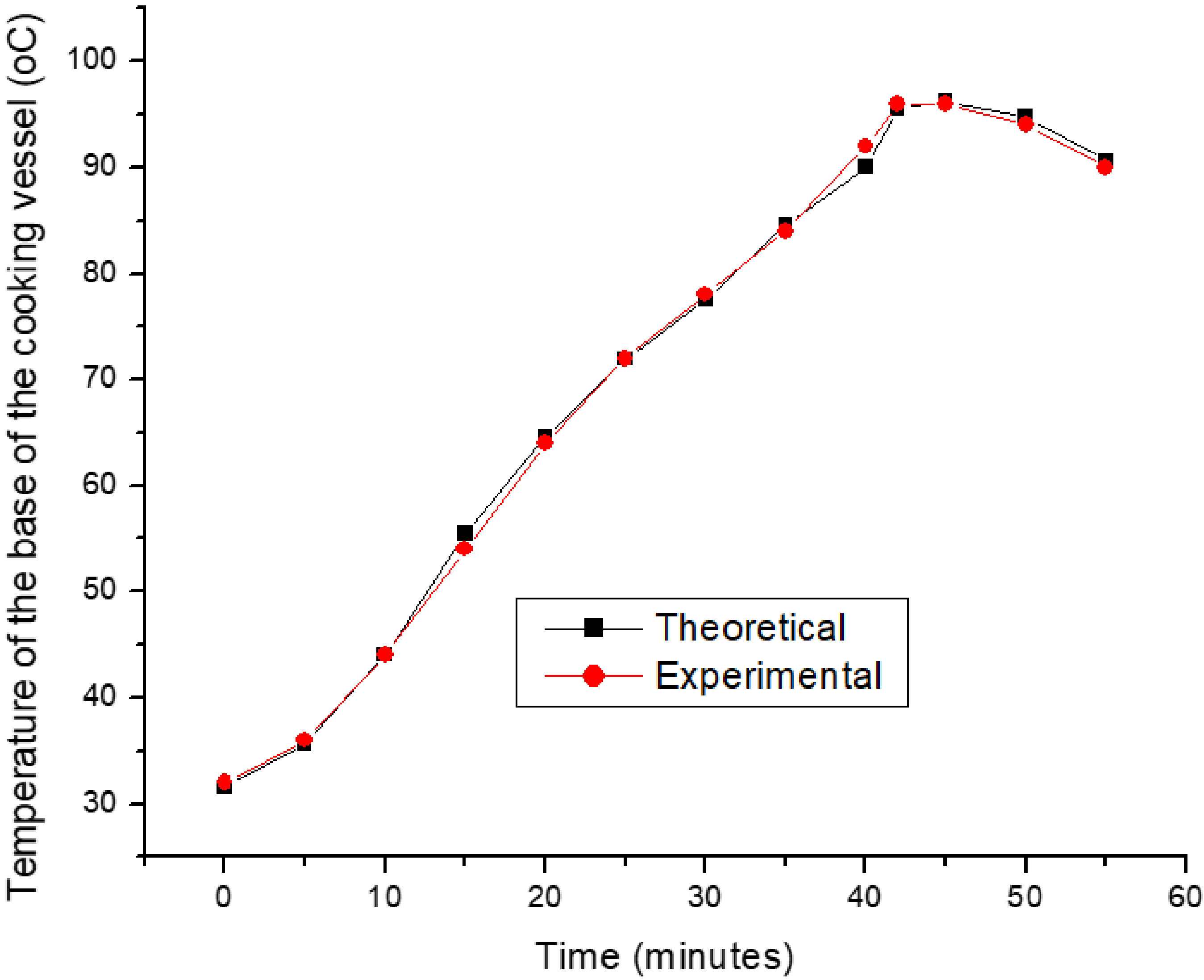

Figure 11

Variation of the temperature of cooking vessel base vs. time.

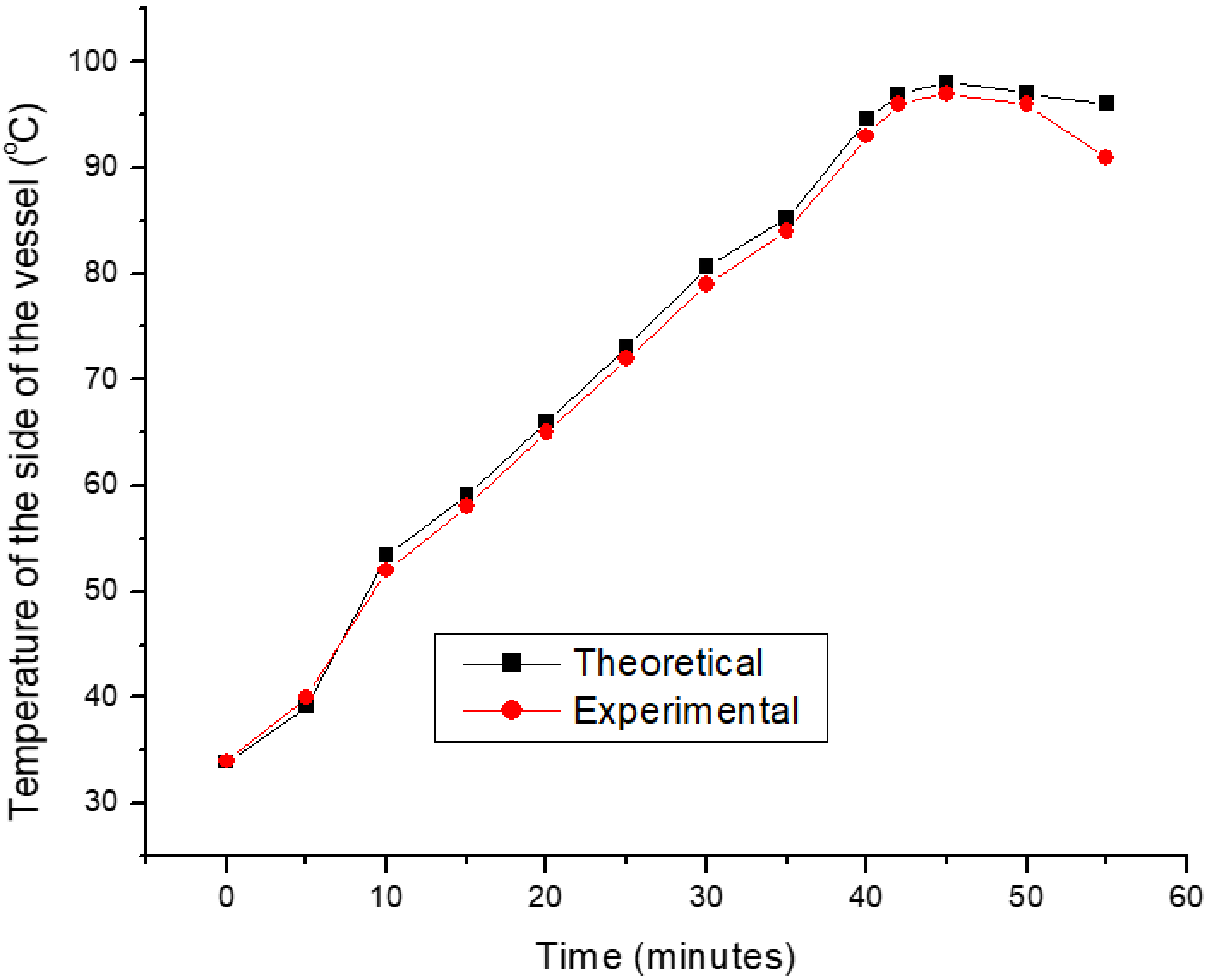

Figure 12

Variation of the temperature of cooking vessel sides vs. time.

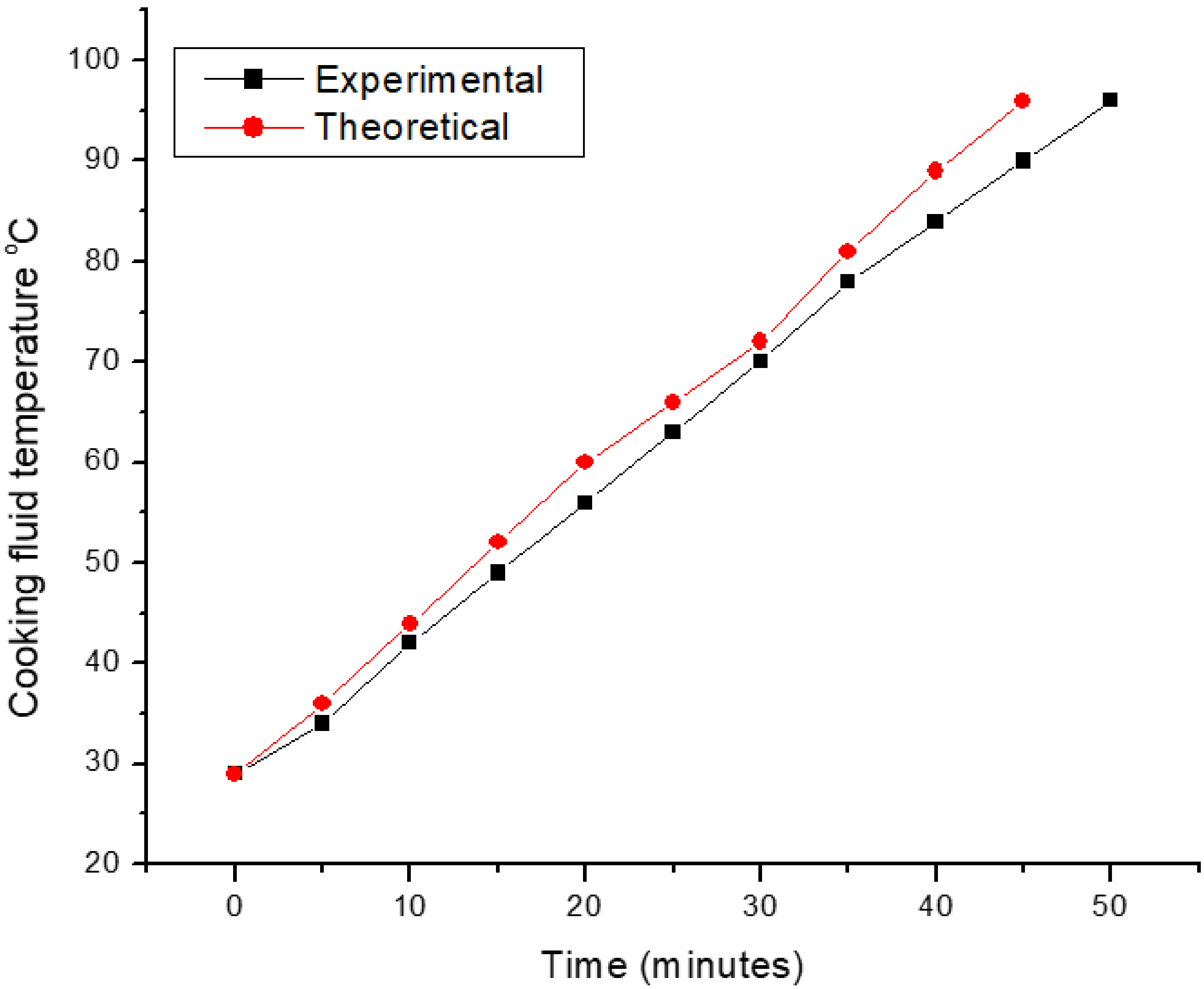

Figure 13

Experimental and theoretical values of temperature of the cooking fluid.