A DIRECT SOLAR FRYER FOR INJERA BAKING APPLICATION

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Summary

Injera is a traditional staple pancake and it is part of the daily dish to most of the one hundred million population in Ethiopia and Eritrea. The conventional baking method uses either biomass in rural areas or Electricity in majority of urban areas. A direct solar fryer for Injera baking application is developed as an alternative to the conventional baking methods. The solar fryer system uses a 1.8m rim diameter dish covered with aluminum reflective sheet. The system employs an aluminum baking plate of 550 mm diameter, 12.5 mm thickness and is equipped with two axis manual tracking. The direct solar fryer model has two possible operational modes; the continuous heating-baking mode and the alternating heating-baking mode. The experimental result show that the initial heating up time in both modes was in the range of 30 to 45 minute and this initial heat up time was comparable to the conventional baking process. In the initial heat up period, the plate has reached an average temperature of 120 to 130 ℃ in the continuous type model and 160 to 180 ℃ in the alternating type model, which was sufficient surface temperature to initiate a baking activity. The baking process in the continuous type model has taken an average of 5 minutes while the subsequent additional heat up time was 2 minutes giving an average baking time of 7 minutes per Injera. The alternating type model has slower heating time at each consecutive baking activity. The direct solar fryer will provide a baking power of 563W with a system thermal efficiency, including the collector efficiency of 37 %.

Key words: Injera, solar baking, Solar Fryer, baking time, baking power, baking energy

1. Introduction

Injera also written as enjera is an endemic staple food in Ethiopia and Eritrea. Injera is made from the flour of tiny grain locally called teff (Eragrostis tef), a species of in the genus Eragrostis, native to Ethiopia and Eritrea [Mekonnen et al, 2014; Aptekar, 2013; Demissie, 2000]. The teff flour is mixed with water, on average of 30 % to 70 % proportion respectively on mass basis and a sourdough as starter. The mixture in the form of runny dough is left to ferment for few days, usually 3 to 5 days. The sourdough starter and the fermentation process makes the Injera to be mildly sour taste. The fermented dough is then baked into large flat pancake by pouring into a hot clay pan. The dough then stays in the hot clay until the water boiling temperature is reached and as a result, water bubbles scape the pancake forming thousands of tiny craters, traditionally referred as 'eyes' giving it spongy honeycomb like structure while the bottom surface, which comes in contact with the baking hot surface, is relatively smooth. The fully cooked injera then becomes thin, soft and slightly spongy.

Injera is part of the daily dish to most of the one hundred million population in Ethiopia and Eritrea. The Injera, placed on flat serving utensil, is consumed with different toppings or stews, traditionally called "wat". There are similar variants to Injera worldwide. Such variant include "*canjeero"* (also known as "*lahooh"* or "*lahoh"* in Somalia and Djibouti [Abdullahi et al, 2001], "*kisra*" in Sudan and South Sudan, "mandazi" in Kenya, "Lahuhua, pita and falafel" in Yemen and the middle east, "Baghrir" or "beghrir" in the Maghreb region, "chapatti" and "puri" in India, pan fried cakes, paratha, vada and mutuan in Asia and tortilla and navaho fry bread in North America [Gallagher, 2011].

Similar to the worldwide pancake frying process, Injera making process is an energy intensive activity. The household sector in Ethiopia accounts for about 89% of the total energy consumption and with 96% of this energy contributed from biomass (firewood, cow dung and agricultural residue) (Energypedia, 2017; Asfafaw et al, 2014; GiZ, 2011). Majority of the domestic energy requirements is for baking and cooking purposes, accounting for about 60% of energy consumption (Gebreegziabher, 2004, 2007; RPTC, 1998). This makes the injera making activity as the most energy-consuming process in every household in Ethiopia.

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Nomenclature

Q_{baking}	*Baking energy [kJ]*
m_{dough}	*Mass of dough [Kg]*
$C_{p,dough}$	*Specific heat capacity of the dough [kJ/(Kg. K)]*
T_{bt}	*Baking temperature [K)*
T_i	*Initial temperature of the dough [K]*
m_w	*Mass of the evaporated water [Kg]*
Δh_{ev}	*Enthalpy of vaporation of water [kJ/Kg]*
x_w	*Moisture content of the dough (water mass fraction) [ ]*
$C_{p,w}$	*Specific heat capacity of water [kJ/(Kg. K)]*
x_t	*Teff mass fraction in the dough [ ]*
$C_{p,t}$	*Specific heat capacity of teff [kJ/(Kg. K)]*
Q_{plate}	*Plate stored energy [kJ]*
P_{plate}	*Plate heating power [kW]*
$t_{process}$	*Time taken for the whole baking process [sec]*
q_s	*Heat flux supplied to the receiver [W/m^2]*
G_b	*Beam irradiance [W/m^2]*
ρ_c	*Reflectance of the concentrating dish [ ]*
$(\tau\alpha)_e$	*Effective transmittance and absorptance of the receiver surface [ ]*
γ_{rsf}	*Receiver shading factor [ ]*
C	*Area concentration ratio [ ]*
$\dot{Q}$	Heat supply to the receiver [W]
A_r	Receiver aperture area [m^2]
A_a	Concentrating satellite dish aperture area [m^2]
η_{opt}	Optical efficiency of the parabolic dish [ ]
Q_{in}	*Input solar energy [kJ]*
h_L	Overall heat transfer coefficient [W/M^2.K]
$\eta_{th,plate}$	Thermal efficiency of the receiver [ ]
$\eta_{th,baking}$	Thermal efficiency of the of the overall baking process [ ]

The conventional baking process mostly employs a traditional large size clay plate (locally called 'mitad') with 500 to 600 mm in diameter and 20mm thickness. This traditional baking clay has relatively low thermal property hence it requires higher amount of heat than for typical for boiling. The conventional baking method uses either biomass in rural areas or Electricity in majority of urban areas. Biomass based baking process is inefficient, poses pollution hazard and it is becoming expensive due to limited biomass resource in the country while electricity access is very low as majority of Ethiopians live off grid. Therefore, the development of alternative technology for Injera baking application will have significant contribution in the energy consumption profile and socio-economic aspect of the country.

From Ethiopian perspective, a solar energy-based technology is the most promising alternative to the existing energy resource for Injera baking application. Injera baking is high-energy intensity application. The baking process occurs in the temperature range of 130 ℃ to 220 ℃ at an energy consumption of approximately 1MJ/kg of Injera and with a baking time of 180 seconds to 240 seconds. Ethiopia is endowed with abundant solar energy, with daily average solar radiation of 5 kWh/m^2 [Anwar et al, 2014]. Solar energy can be converted into thermal energy as per the baking process energy consumption requirement more easily and in a sustainable way than other alternative energy sources such as biomass, wind, hydropower and geothermal energy.

Solar energy based Injera baking technology can be either a direct system [Gallagher, 2011] or an indirect system [Asfafaw et al, 2014; Maxime et al, 2013]. The direct system uses direct illumination of the solar radiation into the illumination surface (bottom surface) of a baking pan while the Injera is baked at its baking surface (the top surface). Such direct system is suitable for outdoor baking activity. The indirect system uses heat transfer fluid (HTF) to transport thermal energy from the solar energy collector and/or absorber to the application, in which case again the HTF may heat the baking plate directly or the thermal energy in the HTF is transferred and stored in other thermal energy storage materials, such as solar salt or thermal oil. The direct system is simpler and cost effective while the indirect system will be more complicated and with high cost. The intention of this study is to develop simple and cost effective direct solar fryer for Injera baking application and analyze the performance of the solar thermal technology.

The Injera baking process would pose two main challenges for any type of solar energy based Injera baking technology. The first challenge is due to the size of the traditional Injera, which is about 50 to 60 cm in diameter. This implies that the baking process demands the provision of uniformly distributed heat on larger size baking pan. This would be a challenge as the solar radiation is reflected into a larger area baking pan while the radiation is being focused from the larger solar concentrators. Furthermore, while Injera is prepared softer and thinner, other variant of pancakes seems to be made thicker and taken drier at the end of the baking process. Due to that, Injera baking process will require relatively more uniformity in temperature distribution over the larger size baking plate. The second challenge is the requirement of high intensity of heating of the baking process. This challenge requires the availability of sufficient beam irradiance and an employment of an appropriate solar collector size.

While many designs of the direct system type exist for cooking application or baking of smaller size staple foods; a solar fryer of large size specifically for injera baking application is designed and reported by Gallagher [Gallagher, 2011]. In this system, a 1.2 m diameter solar collector with quasi focus is employed to heat a 0.46m diameter baking pan, which is designed for cooking 0.42 m diameter slices of injera bread. A mirror below the pan directs the radiation to the pan bottom, which is coated with a low-emissivity black absorber. The mirror uses flat, hexagonal panels of aluminized polyester (Mylar) to provide relatively uniform illumination across most of the pan bottom. The baking pan can be stationary at the quasi focus of the mirror assembly (i.e. simultaneous heating and baking) or it can be taken in or out of the dish in north-south direction while pouring the dough and while removing the baked injera and put back into the dish for heating in the remaining time of the baking process (i.e. discontinuity of heating during the baking process).

One of the main challenges in applying the Gallagher prototype to developing country like Ethiopia is the difficulty and challenge of making the quasi focus solar collector which is comprised of flat and hexagonal mirrors. Therefore, due to manufacturing difficulty, such collector will literally be subjected to significant radiation loss if adapted and redeveloped. In this regard, the core design condition of attaining relatively uniform illumination on the backside of the baking plate will be affected, if not it will be significantly expensive. The second challenge is the upscaling of any concept by itself. In upscaling, the challenge of attaining relatively uniform temperature distribution over the baking surface of the plate has to be addressed either by attaining uniform illumination or by employing baking plate material and optimized plate thickness that will ensure optimum conduction process, in turn that will lead to relatively uniform temperature distribution over the baking surface of the plate.

Traditionally, Ethiopia's Injera is with the size of 500 mm to 600mm in diameter. Therefore, the social acceptance of the traditional staple food demands the development of a solar fryer prototype that will enable to bake an Injera of the above size, while the Gallager prototype is designed for 420 mm slice of Injera. The work by Gallagher is used as a basis for the design and development of a direct solar fryer as reported in detail in this research. This newly developed system is an up scaled and an alternative version while addressing the possibility of conducting solar baking with larger size direct solar fryer. An extensive experimentation of baking process is also conducted and the performance of the system is evaluated. This direct solar fryer system for baking application is with the largest fryer size and no other such large area-frying panel has been reported so far.

2. Design of the direct solar fryer

2.1 Geometrical design of the solar fryer system

The solar fryer system uses a dish, cheap and widely available in the market with 1.8m rim diameter (focal length 0.684 m and dish depth 0.296 m) and by gluing aluminum reflective sheet (Miro high reflective 95) on the dish. The solar fryer is designed for an outdoor application, hence here called a "direct solar fryer". The direct solar fryer is made with a baking pan or plate made of aluminum (through casting process at local workshops). The optimum thickness and the high heat conductivity property of the Aluminum plate ensures there exists relatively uniform temperature distribution on the baking surface of the plate.

The solar fryer model is designed with a baking pan size of 550 mm in diameter and 12.5 mm in thickness. The solar fryer has two possible operational modes. The first operational mode is the configuration that enables simultaneous heating and baking process here referred as "*solar fryer with continuous heating and baking mode*" while the second mode is the configuration that enables heating and baking to be conducted alternatively, here referred as the "*solar fryer with alternating heating and baking mode*". These two modes of the solar fryer are illustrated in figure 1 and figure 2 respectively.

The baking plate can be placed at a distance of 5 to 8 cm distance above or below the focal point, illuminating major part of the heating surface, about 40 to 70% of the plate surface, which gives 25 to 15 concentration ratio respectively. This focusing is done by using the telescopic adjustment structure on the dish support. The plate support structure is also provided with additional rotational motion to allow small inclination during initial heat up period and at consecutive heating and baking periods thus to increase the efficiency of the radiation absorption at the illumination surface of the plate. In the continuous type model, the telescopic adjustment will also help to compensate the seasonal declination of the sun, combined with seasonal translational adjustment of the plate support about orthogonal direction to the axis of rotation of the dish collector.

The system uses two axis manual tracking. The first manual tracking (i.e. the dish rotation about an axis of rotation which pass through the focal point of the dish coupled with the plate rotation during initial heating period) is intermittently adjusted throughout the day. The second manual tracking (i.e. the wheel rotation attained by the roller support coupled with the rotation at the bearing) needs to be adjusted at an average of 10 minutes or at the interval of every baking. In this model, the baking process is conducted under no shading, giving some level of discomfort to the user as a result of the radiation exposure while baking.

2.1.1 Continuous heating and baking mode

The solar fryer with continuous heating and baking mode is indicted in figure 1. In this solar fryer, the baking plate is heated from its bottom surface (i.e. the illumination surface) while baking is conducted at its top surface. The plate can be constantly placed near the focus, enabling simultaneous heating and baking or be moved in and out of the dish for short period during dough pouring and baked Injera removing activity, while in the remaining time the plate will be in heating and baking mode. The choice of these two modes basically depends if the user would like to access the baking plate inside the dish or by moving out of the dish for dough pouring and baked Injera removing activity.

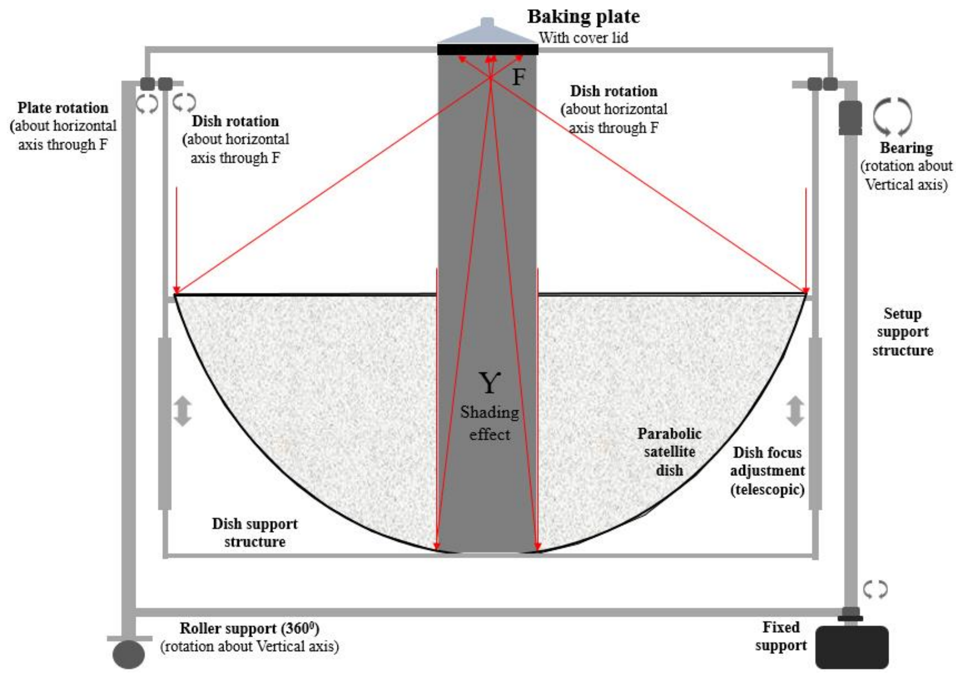

Figure 1: The direct solar fryer with continuous heating and baking mode

2.1.2 Alternative heating and baking mode

The solar fryer with alternative heating and baking mode is indicated in figure 2. In this *model*, heating and baking occurs alternately and on the same surface of the plate, while the backside of the plate is covered with insulation. The plate-dish assembly can easily be rotated at the rim of the dish, which is close to the mass center of the whole assembly. This system provides the baking process to be conducted under the shading of the dish, giving some comfort to the user. In this system, the baking energy requirement is obtained from the stored thermal energy of the plate.

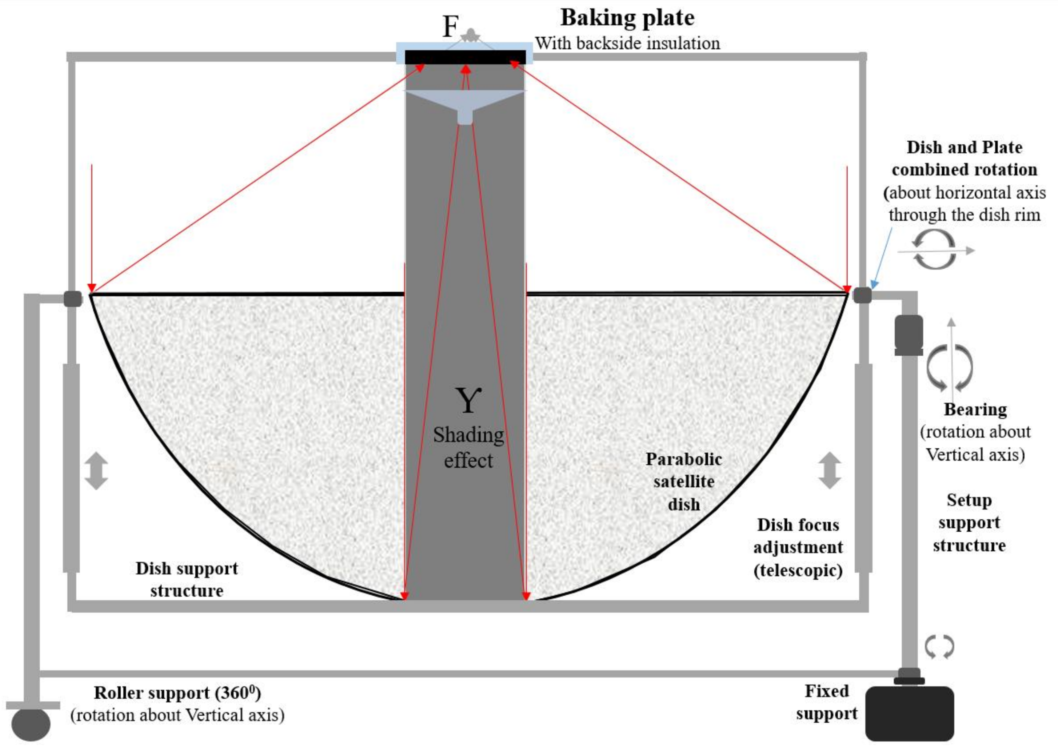

Figure 2: The direct solar fryer with alternative heating and baking mode

2.2 Thermal design of the system solar baking application

The thermal design of the solar fryer is based on the Injera baking energy requirement. An average Injera of 550 mm to 600 mm in diameter is made from 550 g dough, which in turn is made of 70% and 30% proportion (by mass) of water and teff flour respectively. Upon completion of the baking process, the dough is heated from room temperature 25 ℃ to water boiling temperature of 100 ℃ as a result about 25% of the moisture content of the dough is evaporated at the end of the baking process. The baking energy requirement is therefore the thermal energy consumed for raising the temperature of the dough and the latent heat of vaporization of the 25% water content. Mathematically, this baking energy [kJ] can be given by;

$$Q_{baking} = m_{dough}\, C_{p,dough}\, (T_{bt} - T_i) + m_w \Delta h_{ev} \qquad \textit{(Eq. 1)}$$

During the baking process, the mass (m_{dough}) and specific heat capacity ($C_{p,dough}$) of dough varies with time. Therefore an average value for the m_{dough} and $C_{p,dough}$ shall be taken, considering the value of these parameters at the beginning and end of the baking process. The average specific heat capacity of the dough can be given by;

$$C_{p,dough} = x_w\, C_{p,w} + x_t C_{p,t} \qquad \textit{(Eq. 2)}$$

The baking plate is a receiver or an absorber and it acts as a buffer storage during the baking process. This stored energy [KJ] is given by;

$$Q_{plate} = (mC_p)_{plate}\, (T_f - T_i) \qquad \textit{(Eq. 3)}$$

The solar fryer average capacity in terms of heating power can be given by

$$P_{plate} = \frac{Q_{plate}}{t_{process}} \quad (Eq.\ 4)$$

The useful energy of the baking process is the thermal energy consumed for the baking activity, i.e. Q_{baking}. But sometimes, the stored thermal in the baking plate itself can be considered as part of the useful energy. In such case, the total thermal energy from the system will be the sum of the baking energy and the thermal energy stored in the baking plate.

$$Q_{thermal} = Q_{baking} + Q_{plate} \quad (Eq.\ 5)$$

The input energy is the solar radiation falling on the collector. This solar radiation is reflected into the fryer, illuminating major part of the bottom surface of the aluminum plate. The heat is then transferred through conduction radially and vertically to the top surface of the baking plate (3D heat transfer). The optimum thickness and the high heat conductivity property of the Aluminum plate ensures there exists sufficiently uniform temperature distribution on the baking surface of the plate. The heat flux, q_s [W/m^2] and the heat flow rate, $\dot{Q}$ [W] supplied to (received by) the receiver surface is given by;

$$q_s = G_b \rho_c (\tau\alpha)_e \gamma_{rsf} C \quad (Eq.\ 6)$$

$$\dot{Q} = q_s A_r = q_s \frac{A_a}{C} \quad (Eq.\ 7)$$

The receiver shading factor, γ_{rsf} and the optical efficiency of the parabolic solar collector, $\boldsymbol{\eta}_{opt}$ are defined as;

$$\gamma_{rsf} = \frac{A_a}{A_r} = 1 - \frac{1}{C} \quad (Eq.\ 8)$$

$$\eta_{opt} = \rho_c (\tau\alpha)_e \gamma_{rsf} \quad (Eq.\ 9)$$

The thermal energy efficiency of the solar fryer is determined as a ratio of the useful energy to that of the input solar energy. Temperature measurement is taken on the heating and baking surface of the plate in order to determine the heat transfer of the overall baking process.

The input energy to the solar collector, Q_{in}, the useful energy delivered by the collector and gained in the receiver plate, Q_{plate} and the thermal efficiency of the receiver, $\boldsymbol{\eta}_{th,\ plate}$ and the thermal efficiency of the baking process, $\boldsymbol{\eta}_{th,\ baking}$ are given by;

$$Q_{in} = G_b A_a \gamma_{rsf} \quad (Eq.\ 10)$$

$$Q_{plate} = q_s A_r - h_L A_r (T_r - T_a) = \left(mC_p\right)_{plate} \left(T_f - T_i\right) \quad (Eq.\ 11)$$

$$\eta_{th,plate} = \frac{Q_{thermal}}{Q_{in}} \quad (Eq.\ 12)$$

$$\eta_{th,baking} = \frac{Q_{baking}}{Q_{in}} \quad (Eq.\ 13)$$

The *solar fryer mode with* continuous heating and baking mode will have lower heating and baking time hence relatively higher efficiency while in the alternative heating and baking mode the heating and baking time will be larger resulting reduced efficiency.

2.3 Solar tracking and application time

The solar fryer is designed and provided with two application modes. The continuous type model is more preferable for applications areas and time in which the sun is in relatively overhead position thus the dish inclination angle is in the range of ±15^0 from the vertical position. Such conditions can be easily obtained in Ethiopia when the local time is in the range of 10:00 to 15:00. The alternating type model provides more flexible in terms of solar inclination, as heating and baking are conducted alternatively. Therefore, while the alternatively type model is equally applicable in the above time, it is more preferable if an application is required for the remaining time of the day i.e. early morning and late afternoon, provided if there is sufficient solar radiation.

2.4 Injera quality assessment

The performance of the direct solar fryer is also determined qualitatively based on the quality of Injera as compared to quality of Injera baked by conventional baking process, such as electrical baking. The quality of the baked Injera is determined qualitatively by physical inspection of its size (thickness), colour, eye formation, underside appearance, texture and taste. This physical property is qualitatively evaluated with the respective physical property of Injera baked by conventional baking methods, such as electrical mitad.

3. Experimental methods and materials

A prototype developed for the direct solar fryer model is shown in figure 3, with the prototype in a) indicates for the continuous heating and baking mode of operation while the prototype in b) indicates for the alternative heating and baking mode of operation.

a) b)

Figure 3: the direct solar fryer model a) with continuous heating-baking mode b) with alternative heating-baking mode

Extensive experiments on the two models were carried out, thereby to evaluate the thermal performance of the system by conducting temperature measurement on the different points on the baking plate, mass and solar radiation measurement. The experimental setup is shown in figure 4.

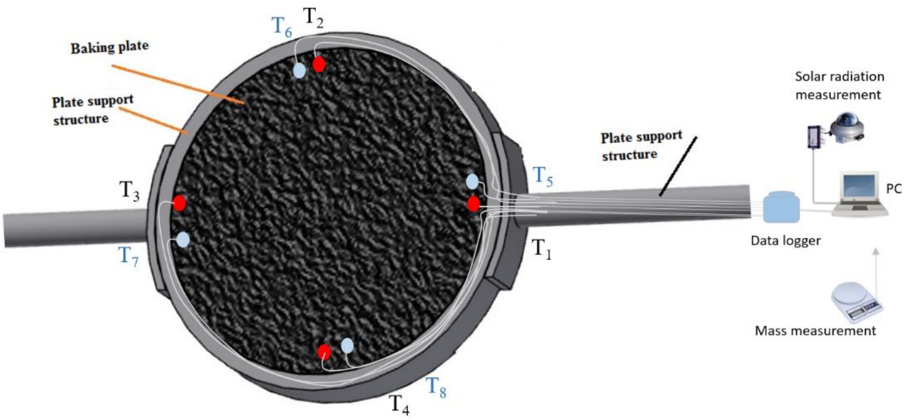

Figure 4: schematics of the experimental setup for temperature, solar radiation and mass measurement

Eight thermocouple (k type) were used to measure temperature at the surface of the baking plate. For the continuous mode, the temperature measurement on the illumination side is denoted as T_1, T_2, T_3 and T_4 and the baking surface as T_5, T_6, T_7 and T_8. Similarly, for the alternative mode, the temperature measurement on the illumination (or baking) side is denoted by T_1, T_2, T_3 and T_4 while the backside (insulated side) of the plate is denoted by T_5, T_6, T_7 and T_8. During the analysis, an average of these temperature measurements were calculated, indicated as $T_{av,\ baking\ surface}$, $T_{av,illumination\ surface}$ and $T_{av,\ plate.}$ Solar radiation measurement using the Delta T instrument (SP1 sunshine pyranometer) were conducted, measuring global (G) and diffuse irradiance (G_d). Mass measurement of the dough and the baked Injera were also taken.

4. Result and discussion

In this research, the thermal performance of the direct solar fryer with two mode of operation i.e. the continuous heating and baking mode and the alternative heating and baking mode is analyzed and presented. The performance of the direct solar fryer is presented in terms of heating-baking temperature profile, power, energy consumption and thermal efficiency, as discussed in the following sections.

4.1 Heating and Baking Temperature Profile

The temperature profile of the heating-baking process for the direct solar fryer model with continuous heating and baking mode is indicated in figure 5. The initial heating up of the plate has taken an average of 30 minutes until it reaches a baking temperature of 120 ℃ to 130 ℃, which was sufficient surface temperature to initiate the baking activity. The heat distribution was also relatively within acceptable uniformity, with an average temperature difference between the bottom illumination and upper baking surface of 3 ℃ while the instantaneous difference was between 0 to 10 ℃.

For the solar fryer with the alternating heating baking mode, the plate has reached an average temperature of 160 to 180 ℃, which was sufficient to initiate the baking process. The average temperature drop per each baking was about 40 ℃ (170-130 ℃), which indicated the thermal energy storage requirement of the baking plate.

In comparison to the conventional baking process, the temperature profile of the heating and baking process was similar as this temperature profile was independent of the type of energy utilized, rather the baking energy requirement of the process.

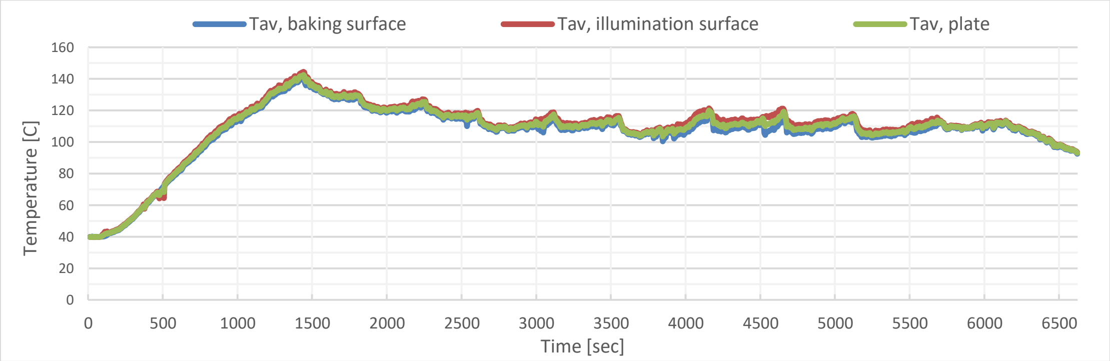

Figure 5: Heating and baking temperature profile for the alternative solar fryer model with continuous heating and baking mode
[Note: the result here is from an experiment taken on March 16, 2017 at Mekelle Ethiopia. Similar result has been obtained on experiments taken on 10th and 11th of February; 15th and 17th of March; 11th, 12th and 13th of May; 16th 17th and 19th of June 2017]

4.2 Heating and Baking Time

As indicated in figure 5, each baking activity using the continuous heating and baking mode fryer has taken an average of 5 minutes while the subsequent additional heat up time is 2 minutes, giving an average baking time of 7 minutes per Injera. The direct solar fryer with the alternating heating and baking mode requires larger heating time at each interval of baking process, as the plate needs to store thermal energy for the subsequent baking process.

In comparison to the conventional baking process, both modes of the direct solar fryer have the same degree of initial heating time. The subsequent heating-baking time for both models is slower than the conventional baking process while the solar fryer with the alternating heating-baking mode is even slower. The conventional baking process usually requires an initial heating time of about 30 minutes while the subsequent heating-baking time is about 3-5 minute per Injera.

4.3 Baking Power and Energy

The heating and baking power requirement for the direct solar fryer model with continuous heating and baking mode is indicated in figure 6. The area under the power curve in figure 6 will give the total thermal energy from the sun, the thermal energy stored in the baking plate and the energy consumption for the baking process. The average plate stored energy was about 153kJ per Injera and this was equivalent to 563W of baking plate power.

The average direct solar intensity has been 932W/m^2 and considering the collector size, this is equivalent to 2kW available energy from the solar radiation. Considering an aluminum material reflectivity of 95 % and other factors (i.e. pan surface reflectance, pan shading effect and dish estimated defect) combined effect of 72% will give 1538 W capacity of incoming radiation from the solar collector, thus about 37 % of the solar radiation reaching the illumination surface was converted into the baking plate power.

The overall energy consumption of the direct solar fryer model with continuous heating and baking mode is indicated in figure 7. The baking energy was determined to be 1150 kJ/Kg of Injera or 450 kJ per Injera. The solar fryer thermal efficiency ($\eta_{th,baking}$) including the solar collector efficiency, was determined to be 37 % while the thermal efficiency ($\eta_{th,plate}$), by including the plate stored energy as a useful energy was about 65%. The low thermal efficiency was attributed as the baking plate is very large (550 mm in diameter and 12.5mm thickness) in order to meet the traditional Injera size, prompting higher surface convective and radiative heat losses. The solar fryer would have been more efficient if it was smaller size but that will have social acceptance problem because of its smaller Injera size. Large size solar fryer compromises efficiency and baking time; the larger the size the less efficient and the larger baking time but it satisfies the traditional Injera size requirement.

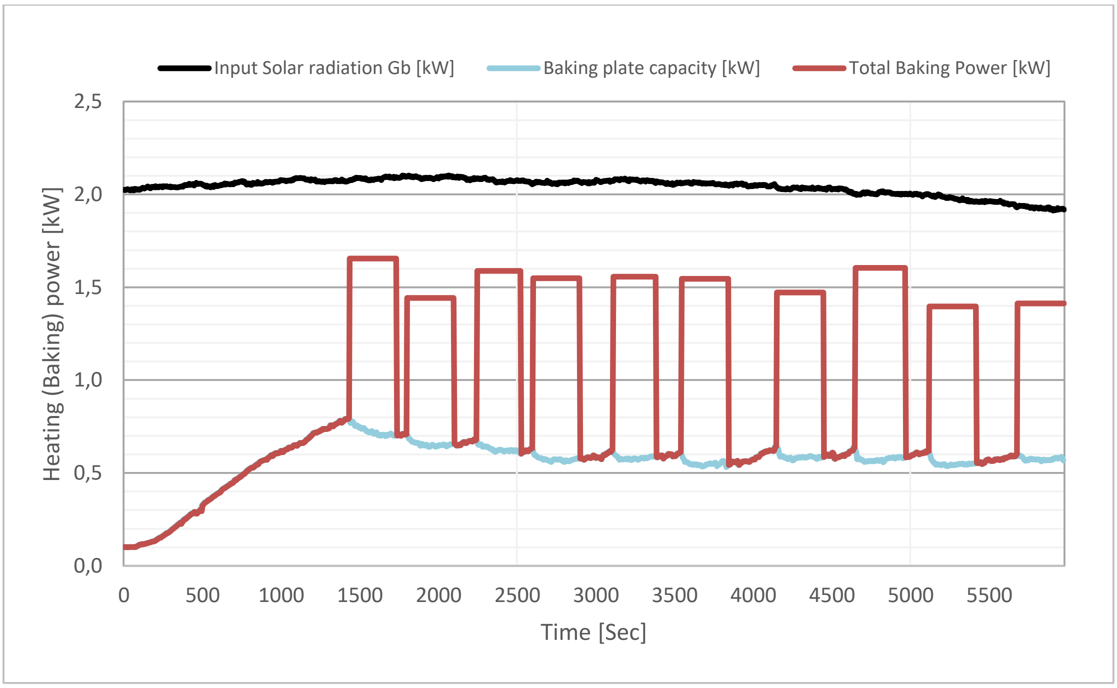

Figure 6: Heating and baking power for the direct solar fryer model with continuous heating and baking mode

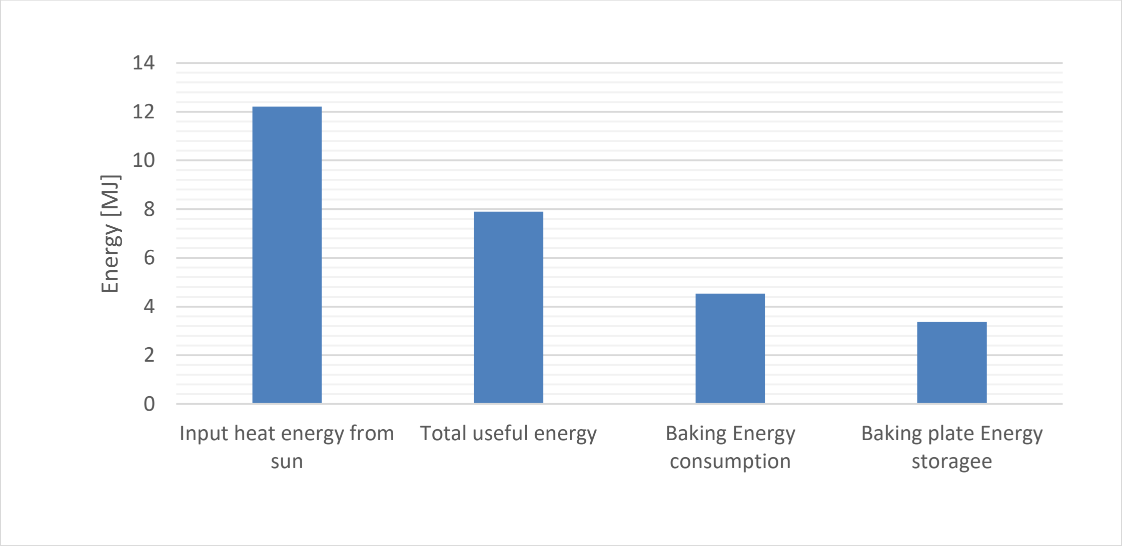

Figure 7: Overall energy consumption of the direct solar fryer with continuous heating and baking mode

4.4 Quality of the Injera

The quality of the baked Injera is as indicated in figure 8. It can be seen that the quality of the Injera with respect to the physical property of size (thickness), color, eye formation, underside appearance, texture and taste is very good and it is the same as any Injera baked with the conventional baking system.

Figure 8: quality of the Injera from the direct solar fryer with continuous heating and baking mode

5. Conclusion

This research has demonstrated solar injera baking using a large size direct solar fryer. The solar fryer was designed to address simplicity in the system and its application. The solar fryer is effective, with 37% thermal efficiency while enabling to harvest cost-free solar energy. The system can be used for injera baking application in a single household, small group rural households or small scale Injera baking business individuals or groups. The only limitation of the application is when there is no sufficient solar radiation such as in cloudy days or if a baking application is required during off sunshine hours, such as at night. For such cases, a backup alternatives should be provided.

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