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Research Article

Investigation of Biogas Energy Yield from Local Food Waste and Integration of Biogas Digester and Baking Stove for Injera Preparation: A Case Study in the University of Gondar Student Cafeteria

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Energy shortage is the main problem while preparing food at the university in Ethiopia. Baking of injera consumes a lot of firewood due to the nature of baking mitad and layout of the system. The daily average firewood consumption is 8600 kg which is equivalent to 790.3 m^3 of gas. In this study, an investigation of energy yield from food waste is examined by assessing the daily waste generation rate from the university student cafeteria and configuring the baking stove (mitad) that utilizes biogas energy. CFD is used to investigate the performance and heat distribution of baking mitad. In the study, the measured average daily biodegradable food waste and kitchen waste generation rate in the campus is around 863 kg/day. The conversion of this food waste using the anaerobic digestion system yields 43.2 m^3 biogas per day. Utilizing the daily biogas generated for baking injera improves the overall food making process and reduces firewood consumption by 5.4%. This biogas energy yield is considered to be utilized for baking injera in the kitchen. The designed biogas mitad (stove) does not generate smoke due to the type of fuel used and configuration of baking mitad. Furthermore, the stove has an insulation mechanism considered to conserve the heat loss to the surrounding. Generally, the utilization of the biogas system and integration of the biogas injera baking stove will improve the overall food processing mechanism in the university.

1. Introduction

In Ethiopia, injera is the main food source which is made from a teff powder. During the process, teff powder is mixed with hot water to create dough; then, the dough is allowed to ferment for days; usually, sourdough starter (yeast) will be added to facilitate fermentation. This fermentation process could take place for 2 to 3 days depending on the temperature of the environment. The injera is then ready to be baked into large flat surface called mitad. The dough is liquid enough to pour into the flat surface of the baking stove (mitad); the flat pancakes (injera) will have a smooth texture in the bottom side, the side that has direct contact with the stove (mitad); and the upper surface creates a porous-like profile called eye. The quality of injera is also characterized by the uniform porosity (eye) created on the upper surface of the injera [1]. This baking process is commonly made by a biomass-operated stove (i.e., three-stone fireplace and improved injera baking stoves), on a clay plate known as mitad. Injera baking using a three-stone fireplace as shown in Figure 1 is very inefficient and consumes a lot of firewood. Additionally, it creates a health problem such as lung cancer due to smoke generated. In this study, the injera baking process is designed to be made using a biogas stove specially designed to consume biogas fuel. The designed system generates no smoke, and its efficiency is improved due to the addition of the insulation system and different layout used.

The designed biogas stove is mainly comprised of an injector, burner, and gas/air mixing chamber as shown in Figure 2. Inside the air/gas mixing chamber, there is a nozzle

Figure 1: Atse Fasil Campus cafeteria kitchen while baking injera from firewood.

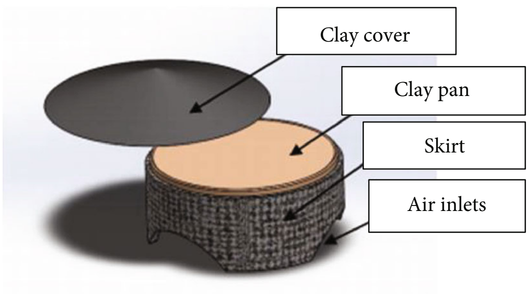

Figure 2: Biogas injera baking stove.

with an injector tapered into it as shown in Figure 3. Inside the burner head, the air/gas mixing chamber outlet is placed vertically to the surface of the burner head. The amount of air that enters the chamber maintains the combustion; it can be regulated by moving the injector into and out of the air/gas chamber, so the injector should be moved out of the air/gas mixing chamber to increase the rise of oxygen into it. The biogas injera baking stove has the same operating principle as a conventional biogas cookstove except for its size and insulation system. Its higher energy duty results in a considerably larger burner with a different configuration to have steady heat distribution throughout the claypan (mitad) [2]. Under this study, daily food waste that is dropped at the backyard of the university student cafeteria is used for biogas generation. Biogas is produced when anaerobic digestion of organic matter like food waste, kitchen waste, and other biodegradable waste is digested under anaerobic condition. Biogas mainly consists of methane and carbon dioxide with a small quantity of gas such as hydrogen. It is colorless but while cooking it has a blue burning flame [3]. The feed stoke used for conversion of biomass waste to biogas can be different depending on the availability of the waste at the local site, but the rate of methane yield depends on the property of the biomass type and digester type used [4].

Under this study, the integration of biogas stove/mitad with a biogas burner that utilizes biogas fuel for baking injera purpose is investigated. As a result, the overefficiency of the injera baking stove is measured as the ability of mitad (injera baking stove) to convert the energy from biogas (fuel) into energy gained by the baked injera. The burning efficiency of the stove is measured as the capacity of the stove to convert the energy from biogas fuel into heat energy [5].

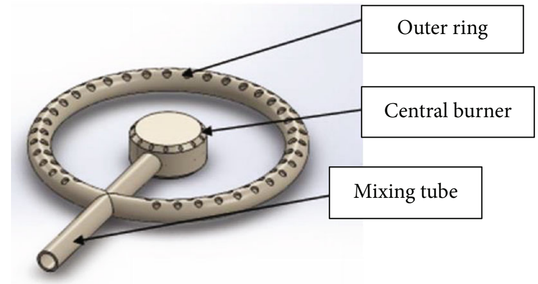

Figure 3: Biogas stove burner.

2. Assessment of Energy Usage: A Case Study in University of Gondar Student Cafeteria

2.1. Energy Source Used for Baking and Cooking Application. In Ethiopia, a governmental university has to provide food throughout the year for their student enrolled regularly; injera and wot (traditional food that can be prepared from meat, grain, etc.) are the main source of meal consumed in a daily basis, doing so requires an enormous amount of energy per day. However, the kitchen tends to prepare the meal using firewood as the main energy resource as shown in Figure 1; burning the firewood beneath the traditional stove for cooking and baking is the main mechanism used as a preparation of food. Firewood is used as a source of energy for baking injera, and cooking is required around 2500 kuntal of wood every month; each kuntal of wood costs around 158 birrs without including transportation cost. Despite the high cost of buying the firewood, its main problem is deforestation leading to environmental effects as well as soil degradation. The smoke produced from the firewood in combustion in the cafeteria using a traditional three-stone fireplace that lacks any provision for smoke exhaust exposes particularly women to smoke containing harmful products. Prolonged exposure to smoke is responsible for coughing, wheezing, acute respiratory infection, chronic obstructive lung disease, adverse pregnancy outcomes, and lung cancer [2].

2.2. Waste Generation and Removal System. In the campus, there are two major sources of waste: waste that comes from the student's food and waste that comes from the kitchen. The collected waste from the two main segments is dropped at the backyard of the kitchen as shown in Figure 4.

3. Material and Methods

3.1. Assessment of Waste and Collection from Kitchen and Student Cafeteria. The current number of students enrolled to use the Atse Fasil Campus cafeteria is around 3045; as a result, a huge amount of kitchen and food wastes is discharged daily. The appropriate amount of waste available and its type should be known before the design of the digester. Accordingly, collecting data has been made through

Figure 4: Food and kitchen waste removal in Atse Fasil Campus cafeteria.

Table 1: Type of solid wastes available and its description in the cafeteria.

Number	Kinds of waste	Description
1	Food waste	Food waste consists of fruit and food scrap obtained from a student after mealtime
2	Kitchen waste	Kitchen waste consists of vegetable waste or peel obtained from the preparation of food

direct measurement of the waste using a balance at the disposal site. The solid wastes in the cafeteria are collected from two different segments as shown in Table 1.

3.1.1. Organic Solid Waste Data Collected. The maximum amount of solid organic waste obtained per day that contains both biodegradable and nonbiodegradable wastes from direct measurement using a balance is recorded as follows for only six days in 2019. The measurement was taken from two campuses as shown in Table 2 and Table 3.

(1) Assumptions.

(i) Consider 15% of kitchen waste is nonbiodegradable

(ii) Consider 95% of food waste is biodegradable

3.1.2. Daily Firewood Consumption for Cooking and Baking. The source of energy for cooking and baking is mainly consumed from firewood collected from the local forest by a contractor. Therefore, the firewood consumed for food preparation for 10 consecutive days is shown in Table 4.

3.1.3. Analysis of Waste Obtained from Food and Kitchen. The data obtained from Tables 2 and 3 shows 95% of the food wastes are biodegradable and 85% of kitchen wastes are biodegradable. Therefore, the total mass of biodegradable waste can be calculated as follows:

(1) Total mass of food waste per day from two campuses = 765 kg/day

(2) Total mass of kitchen waste per day from two campuses = 160 kg/day

(3) The total mass of biodegradable food waste = 95% ∗ 765 kg = 727 kg/day

(4) The total mass of biodegradable kitchen waste = 85 % ∗ 160 = 130 kg/day

(5) Then, the overall total mass of biodegradable waste = 727 kg + 130 kg = 863 kg/day

By using the total mass of biodegradable waste collected per day and property of waste type, the digester size and gas yield will be determined.

3.1.4. Biogas Energy Yield (Biogas Production from Food Waste). Biogas energy yield is found from the product of the overall total mass of biodegradable waste obtained per day and gas production rate from food waste found from physical property listed in Table 5.

The gas produced from food waste per day = 863 kg × 0.05 m^3/kg = 43.2 m^3/day.

3.1.5. Daily Total Volumetric Flow Rate (S_d) in Cubic Meter per Day.

$$s_{\mathrm{d}} = \frac{\text{Total mass of biodegradable waste}}{\text{The density of food waste}}. \tag{1}$$

Using Equation (1) and a physical property listed in Table 5, the daily total volumetric flow rate (S_{d}) is found to be 0.74 m^3/day. The fluid content in the waste is relatively good compared to other types of waste; as a result, applying a one-to-one dilution ratio to make the waste more mixable is important, so 0.74 m^3/d of water is added. Therefore, the volume of the daily charge (S_{d}) is 1.48 m^3/d. Then, using the above daily flow rate, the size volume of the digester (V_{D}) will be determined which is defined as the product of the volume of the daily charge (S_{d}) and hydraulic retention

Table 2: Recorded food waste per day for six consecutive days at campus 1.

No.	Date	Number of waste per bermill (barrel)	Remark
1	23/08/2019	4	
2	24/08/2019	5	
3	25/08/2019	4	
4	26/08/2019	5	Fasting
5	27/08/2019	5	
6	28/08/2019	5	Fasting
		Average 4	

Note: 1 bermill (barrel) = 85 kg (estimation). Then, amount of food waste = 4 * 85 kg = 340 kg/day. Kitchen waste in Fasil Campus (campus 1) weights 80 kg per day.

Table 3: Recorded sample of food waste per day for six consecutive days at campus 2.

Number	Date	Number of waste per bermill (barrel)
1	23/08/2019	6
2	24/08/2019	5
3	25/08/2019	5
4	26/08/2019	5
5	27/08/2019	6
6	28/08/2019	5
		Average = 5

Note: the amount food waste = 5 * 85 kg = 425 kg/day. Kitchen waste in Tewodros Campus (campus 2) weights 80 kg per day. Remark.

Table 4: Firewood used in Atse Fasil Campus per day for 10 consecutive days.

No.	Date	Kuntal	Kilogram
1	21/08/2019	82	8200 kg
2	22/08/2019	84	8400 kg
3	23/08/2019	81	8100kg
4	24/08/2019	88	8800 kg
5	25/08/2019	89	8900 kg
6	26/08/2019	84	8400 kg
7	27/08/2019	80	8000 kg
8	28/08/2019	82	8200 kg
9	29/08/2019	81	8100kg
10	30/08/2019	85	8500 kg
		Average = 84 kuntal/day	

Note: 1 kuntal = 100 kg. Therefore, the total amount of firewood consumed for baking and cooking in Atse Fasil Campus per day is 84 * 100 kg = 8400 kg/day.

time (HRT) [7]. Then, using Equation (2), the digester size is 36 m^3 per day [8].

$$V_D = S_d * \text{HRT}. \quad (2)$$

3.1.6. Balancing Biogas Production and Energy Demand. The quantity, quality, and type of biomass available for use in the biogas plant are the basic factor of biogas generation. The gas produced from food waste per day is the product of food waste per day and its gas production rate [8].

Table 5: Basic information on the physical properties of the substances [6].

No.	Type	Quantity
1	Density of food waste	1160 kg/m^3
2	Density of human waste	1000 kg/m^3
4	Water content of the human manure	90%
5	Water content of urine	94%
6	Organic content of food waste	85%
7	Energy content of biogas	38 MJ/m^3
8	Gas production rate from human waste	0.078 m^3/kg
9	Gas production rate from food waste	0.05 m^3/kg
10	Retention time from food waste	24 days

Table 6: Various weight of dough measured at different times.

Measurements	Weight of dough (gm)	60% water (gm)	40% teff (gm)
1	600 gm	360	240
2	620 gm	372	248
3	595 gm	357	238
4	580 gm	348	232
Average	598 gm	359	240

3.1.7. Determining the Energy Demand. Determining biogas demand is based on present energy consumption, e.g., for ascertaining the baking energy demand. This involves either measuring or inquiring the present rate of energy consumption in the form of wood, charcoal, kerosene, and bottled gas, calculating biogas demand via comparable-use data.

3.1.8. Total Gas Required. The total energy consumption for cooking and heating purpose (E_c) = energy from firewood + energy from dung cakes + energy from charcoal + energy from LPG + energy from butane gas + energy from electricity [8].

Energy from firewood = 8300 kg/day; energy used for baking from firewood is 1/3 of the total consumption used for making food which is around 2766 kg/day.

One cubic of biogas = 3.5 kg of firewood. Then, 1 m^3 biogas * 2766 kg/3.5 kg = 790.28 m^3.

3.2. Analysis of Biogas Stove and Burner for Gas Produced. Under this study, a biogas burner is designed based on the maximum daily generation of gas from this plant. During the analysis, the data are collected through direct measurement and secondary data from GIZ; it expresses that the amount of water and teff in dough is 60% and 40%, respectively. During the actual measurement, the weight of the dough measured has a slight variation in gram while baking injera as shown in Table 6 [8].

Based on the assessment made for injera baking, the average mass of the dough is around 598 grams per each injera baked. Estimation of energy demand for injera baking with dough (Q) is found from the equation [9].

$$Q = m\text{dough} \times Cp,\text{dough}\frac{T2 - T1}{t}. \quad (3)$$

3.2.1. Assessment of Biogas Flow Rate through a Stove Burner. The average power required for baking injera on mitad for a typical baking of mitad of 60 cm in diameter and efficiency of 25% is found from Equation (4) [9].

$$p_{\text{required}} = \frac{p_{\text{out}}}{\text{efficency}}. \quad (4)$$

Then, the output power from flame combustion required to bake injera is 5.696 kW. Then, the biogas flow rate (Q_{gas}) is determined as follows:

$$Q_{\text{gas}} = \frac{\text{energy needed}}{\text{calorific value}}. \quad (5)$$

One volume of methane requires two volumes of oxygen, to give one volume of carbon dioxide and two volumes of steam. Since there is 58% methane in biogas and 21% oxygen in air, $1/0.58 = 1.72$ volume of biogas requires $2/0.21 = 9.52$ volume of air or one volume of biogas requires $9.52/1.72 = 5.5$ volume of air (stoichiometric air requirement). From the complete combustion process, the stoichiometric primary aeration required is 5.5; then, the entrainment ratio r should be $r = 5.5/2 = 2.75$ [10]. The mixture flow rate at optimum aeration is found from Equation (6) [5].

$$Q_m = (1 + r)3600. \quad (6)$$

3.2.2. Pressure Drop in a Mixing Chamber. The pressure drop in the mixing tube, which should be at least 315 mm long ($15 \times d_t$), can be calculated as follows:

$$\Delta P = \frac{f}{2}\rho\frac{16Q_m^2}{\pi^2 \times d_t^5}. \quad (7)$$

3.2.3. Burner Port Design. Burner port is at which the gas flows from it and burnt. It is more affected by high temperature, and the material selected for this purpose, stainless steel, resists a temperature of flame. So, using Equation (9), the area of the port is 0.00384 m^2 [2].

$$Ap = \frac{Q_m}{0.25}. \quad (8)$$

The number of ports required for efficient utilization of gas into mitad surface is found from Equation (9) [2].

$$np = \frac{4Ap}{\pi d_p^2}. \quad (9)$$

Table 7: Dimension of the burner major component.

No.	Component	Symbol	Value
1	Orifice injector diameter	d_o	3 mm
2	Orifice channel length	b	4.5 mm
3	Throat diameter	(dt)	18 mm
4	Length of the mixing chamber	(L)	30 mm
5	Length of air intake hole	$L_{\max}$	140 mm
6	Diameter of the mixing chamber	(D)	26 mm

The analysis of the burner is conduced based on the maximum gas flow rate, and the geometrical setup for a major component of the burner is listed in Table 7.

3.2.4. Flame Height Determination. The main "combustion zone" is where the gas burns in the primary air and generates the heat in the flame. The "outer mantle" of the flame is where combustion is completed with the aid of the secondary air that is drawn into the flame from the sides.

The combustion products (carbon dioxide and steam) are at a high temperature, so rise vertically away from the flame, transferring heat to the air close to the top of the flame. It is this air moving vertically away that draws in the cooler secondary air to the base of the flame. The size of the inner cone depends on the primary aeration. A high proportion of primary air makes the flame much smaller and concentrated, giving higher flame temperatures [11].

The flame height (L_f) is related to the heat released (Q) rate with the diameter of flame D_f. The calculation of flame length is as follows:

$$L = 0.235Q^{2/5} - 1.02D. \quad (10)$$

4. Result and Discussion

4.1. Assessment and Sizing of a Biogas Digester Based on Available Waste. Among the various types of digesters, in this section of the design, fixed dome torispherical, a continuous feed (displacement) digester is selected for the reason that relatively small amounts of slurry (a mixture of manure and water) are added daily. This enables that gas and fertilizers are produced continuously and predictably. After selecting the type of digester, the retention time, which is a key parameter in determining digester size, is chosen to maximize the percentage of production of biogas with respect to the retention time. 24 days is chosen as the minimum amount of time for sufficient bacterial action to take place to produce biogas and to destroy many of the toxic pathogens found in human waste, considering the diameter (d) and height (h) of mixing pit are equal ($d = h$). The geometry of the digester major components and mixing chamber shown in Table 8 is based on designation in Figure 5.

The mixing pit of the digester should have a size slightly greater than the daily input and better if no corners; therefore, by considering 10% factor of safety from daily input, the volume of the mixing pit is around 1.628 m^3.

Table 8: Digester component volume and diameter.

Component	Symbol	Volume
Mixing pit	V	$1.628\,m^3$
Compensation tank	$V_{tank} = V2$	$8\,m^3$
Gas collecting chamber	V_c	$1.8\,m^3$
Gas storage chamber	V_{gs}	$18\,m^3$
Fermentation chamber	$V_f = V3$	$29.5\,m^3$
Volume of slurry	V_s	$6.5\,m^3$

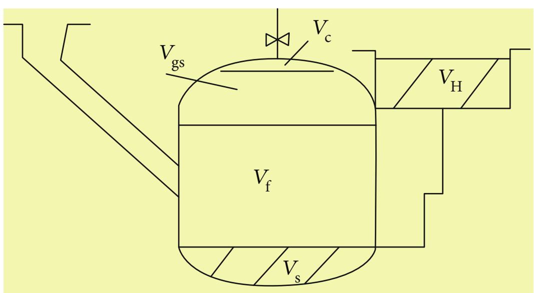

Figure 5: Biogas digester geometry configuration [2].

The dimension of the compensation tank (V_{tank}) is around 20% of the digester (fermentation chamber and volume of slurry), and using Equation (11), it is found to be around $8\,m^3$ [2].

$$V_{tank} = 0.20 * VD. \tag{11}$$

In the analysis, for efficient spaces, the utilization cubic shape of the compensation tank is considered. For $36\,m^3$ digester size, $8\,m^3$ compensation tank is bigger in size but the daily feed stoke will increase following an increase in waste disposal resulted due to an increase in student number.

4.1.1. Pressure in the Gas Holder or Container. This maximum pressure is limited by the lower slurry level (LSL). When pressure increases to the point whereby the lower slurry level (LSL) is pushed down further below the beam/outlet pipe level, biogas will escape through the compensation chamber.

According to the analysis, the pressure inside the digester is 74.2 kPa. This is found from the assumption that the gas in the gas holder obeys the ideal gas law, i.e., $PV = nRT$; the molecular mass of the gas is 25.8 (65% CH_4 and 35% CO_2) and a density of $1.15\,kg/m^3$. The temperature of the gas is 301 K which is slightly higher than the ambient temperature [2]. The slurry is open to the atmosphere, and its pressure is equal to the atmospheric pressure of 101.1 kPa. As a result, the gas in the container will not escape from the gas holder since its pressure is lower than the pressure in the slurry.

4.1.2. Flow Rate of Gas from a Baking Stove Port. The average mass of the dough is around 598 grams per each injera baked. Using Equation (3) and property listed in Table 9, the energy demand for baking injera is 1.424 kW. The energy demand is calculated based on the actual measurement taken during the baking of injera in the cafeteria. It was also found that for an assessment made during baking, the average time required to make injera is 120 seconds, the mass of water is 0.359 kg, and the mass of teff is 0.239 kg, since the dough contains 60% of water and 40% of teff.

Table 9: Measured value for some property during the baking of injera.

Property	Symbol	Value
Specific heat of water at 100°C	Cp w	4.174 kJ/kg °C
Specific heat of teff at 100°C	Cp teff	1.046 kJ/kg °C
Combustion temperature	T2	126°C
Room/ambient temperature	T1	28°C

So, in order to attain the energy required by the baking stove which is 1.424 kW, the biogas flow rate into the burner port has to be maintained at a rate of $0.93\,m^3/hr$, found from Equation (5). The size and shape of the injector orifice control the gas flow rate and hence heat input for a given gas composition and supply pressure. The sitting of the injector with respect to the mixing tube affects air entrainment, so the injector must be positioned with a high degree of precision.

In the analysis, maintaining the heat distribution at a rate of 1.424 kW will make the injera to be baked without changing its natural taste. The upper surface of the injera has to be rough and has a porous-like feature called eye, so this heat distribution will maintain the injera to create eye in the upper surface.

4.1.3. The Gas Pressure in the Throat. The gas pressure in the throat is 99 kPa, which is found from the parameter labeled in table and Equation (12).

$$p_t = p_o - \rho \frac{v_o^2}{2 \times g} \left[1 - \left(\frac{d_o}{d_t} \right)^4 \right]. \tag{12}$$

4.1.4. Pressure Drop in a Mixing Chamber. The pressure drop in the mixing tube, which should be at least 315 mm long ($15 \times d_t$) [2], can be calculated as follows:

$$\Delta P = \frac{f}{2} \rho \frac{16 Q_m^2}{\pi^2 \times d_t^5}. \tag{13}$$

The pressure drop due to the flow of the mixture in the mixing tube is checked, by first calculating the Reynolds number; then, the flow type is found to be laminar. In this study, the pressure drop is 2.57 Pa by considering the geometry shown in Figure 6; this pressure drop is much less than the pressure in the throat; thus, it is good to proceed.

4.1.5. Burner Port Design. If the diameter of the port is higher, there could be a problem in flame lift. Using 5 mm diameter holes to minimize the problem of flame lift, the total number of port found from Equation (9) is 195, as shown in Figure 6.

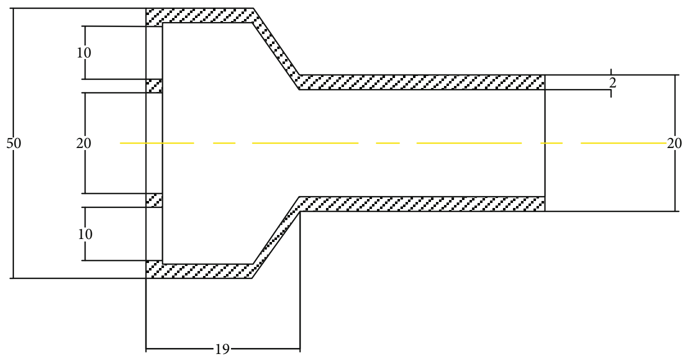

FIGURE 6: Mixing chamber geometry.

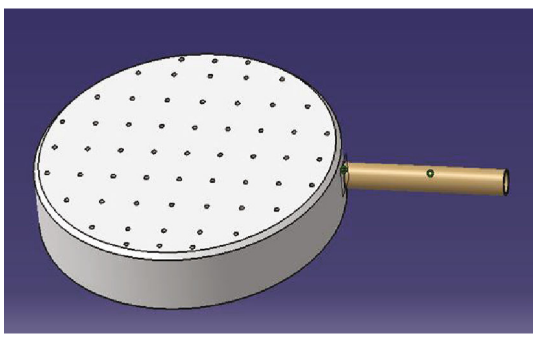

FIGURE 7: Burner port and gas/air inlet pipe.

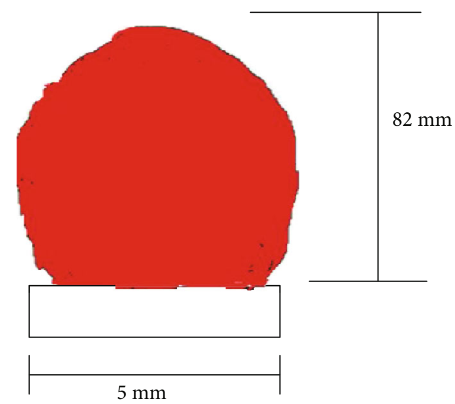

FIGURE 8: Flame height

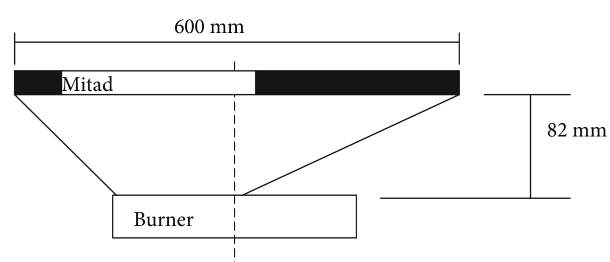

FIGURE 9: Heat transfer between burner and mitad by radiation.

Using the flame stabilization, it should be possible to reduce this number of burner ports by up to 1/3, so 65 holes may be sufficient. The biogas stove does use 65 holes at 5 mm diameters (total burner port area = 12.96 m^2) set at 90° to the vertical, and the flames are fairly expanded on the left area. A larger burner port area would allow for greater flame stability [10].

Using 49 holes, with 10 mm gaps between holes, arranged in a circular pattern, gives a total circumference of $65(10 + 5) = 975$ mm as shown in Figure 7. The hole centers are then placed around a circle of diameter 310 mm. Using more burner ports of the same diameter would mean a larger circle and a larger area over which the heat is distributed. This burner port size allows the biogas to flow into the baking mitad evenly. The shape of the burner port is critical for efficient utilization of the biogas fuel so the designed burner port is believed to discharge the fuel from the pipeline without loss.

4.1.6. Flame Stabilization from a Burner Port Outlet. The output power from flame combustion required to bake injera is 5.696 kW. So, by assuming an even distribution of gas in all 65 ports, each port is expected to deliver heat at a rate of 0.087 kW. Therefore, the length of the flame that passes through each hole is 82 mm, found as in Equation (10) as shown in Figure 8.

4.1.7. Radiation Intensity and Shape Factor Determination between Burner and Mitad. The heat radiates from a burner of 20 cm to mitad of 60 cm diameter, and the space between them is the height of flame determined 82 mm as shown in Figure 9. The temperature inside the baking room is 35°C which is greater than the normal ambient temperature. Then, in order to reduce the rate of heat loss through the wall, an insulator with a wall radius of 0.35 m is considered. The heat flow through the wall is $Q = 0.506$ kW, found from the following:

$$\dot{Q} = \frac{800 - T_o}{0.2 + 6.6 \ln (r_3/0.301) + (0.11/r_3)}. \quad (14)$$

The intensity leaving the burner is 2.394×10^4 W/m^2, found from the following:

$$I = \frac{\sigma T^4}{\pi}. \quad (15)$$

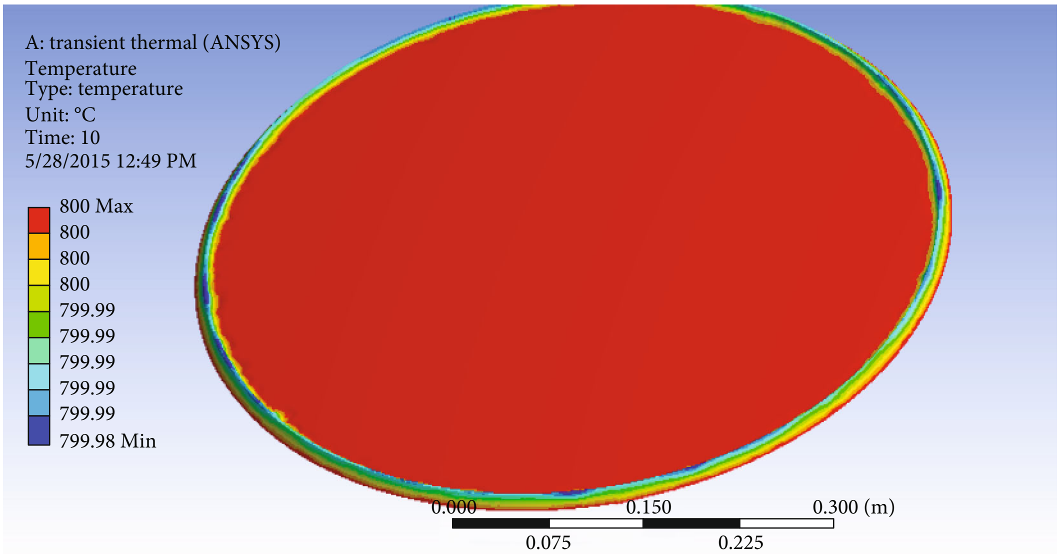

FIGURE 10: Transient thermal analyses over the mitad.

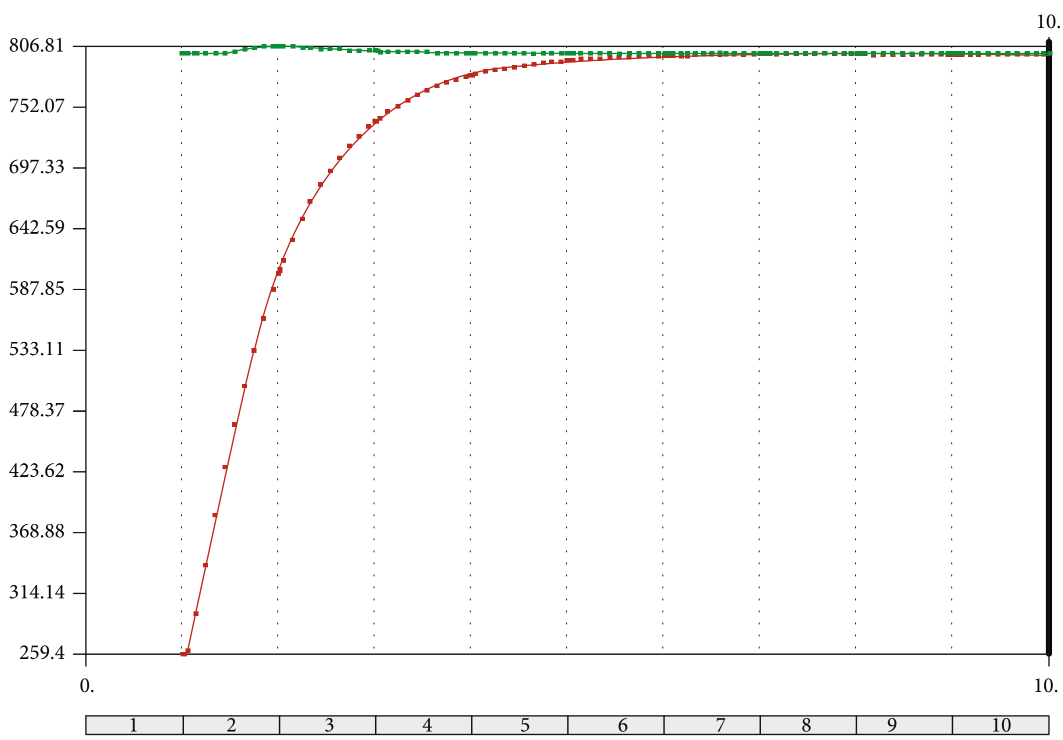

FIGURE 11: Overall temperature distribution over the mitad.

The shape factor is the heat flow through the stove per unit area of mitad; using Equation (16), it is found to be 1.79 kW/m^2.

$$\text{Shape factor} = \frac{Q}{\text{area of mitad}}. \qquad (16)$$

In the analysis, maintaining the flame height at the indicated height beneath the baking stove creates required heat for the baking stove at the desired rate; this makes injera to be baked properly.

4.1.8. Temperature Distribution on Injera Baking Mitad. Using the value of intensity and shape factor, transient thermal analysis and heat distribution over the surface of the mitad are demonstrated. The distributions of heat over the mitad (baking stove) for 120 seconds are demonstrated shown in Figure 10. The temperature distribution over the

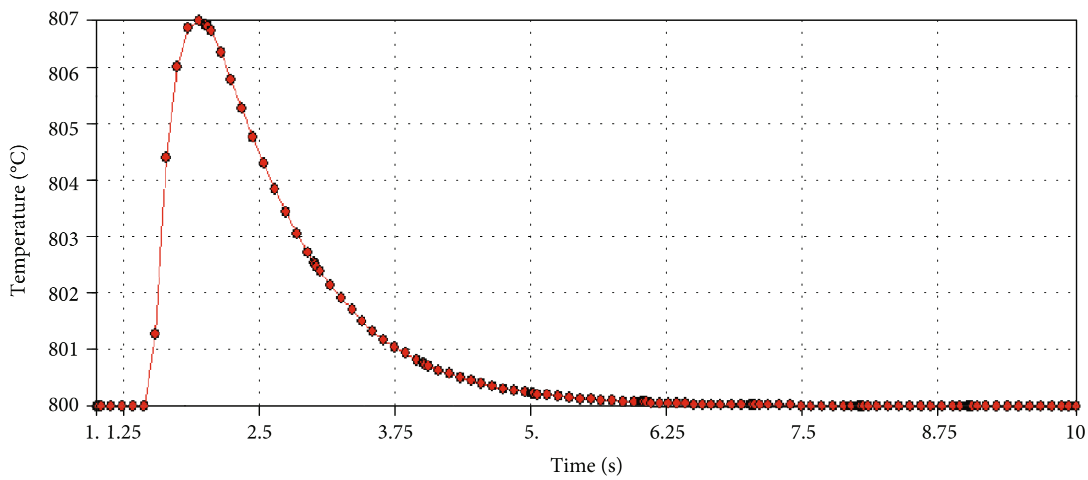

Figure 12: Global maximum temperature distribution over the mitad.

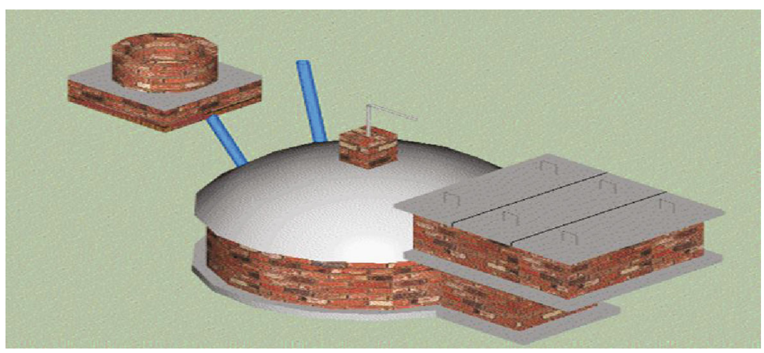

Figure 13: Biogas digester with a mixing pit and slurry outlet.

mitad is analyzed for 120 seconds which is the same as the actual measured value.

The simulated result in Figure 11 shows the heat distribution over the mitad under no baking condition. The heat radiates at a rate of 1.79 kW/m^2 to the bottom surface of 60 cm mitad. In the analysis, the temperature of mitad starts to raise to baking initial temperature of 294.4°C to maximum baking temperature of 806.8°C. Baking mitad performance designed in this study has a similar operating system to that of an actual baking process except for their difference in fuel consumption type and layout.

When the dough is poured on the surface of the mitad, the temperature of the mitad starts to drop due to the fact that the baking mitad upper surface starts to absorb moisture from the wet dough. Then, after 5 seconds, the temperature of the baking mitad starts to flatten to a constant baking temperature of 800°C, as shown in Figure 12. After a while, the heat from the mitad will absorb the moisture content fully from the dough and bottom surface of injera creating a dry and smooth profile.

4.1.9. Integration of a Biogas Digester and Burner Stove. Integration of a biogas digester to a baking stove is made by a pipe for the delivery of the methane gas to the end user. The type of pipe used for this system depends on the environmental condition of the site and location of the digester to the burner stove. However, PVC pipe and PPR pipe are the typical pipeline used for this system.

The gas will leave the digester at a pressure of 74.2 kPa from the gas holder as shown in Figure 13. However, the designed pressure in the throat is 99 kPa, so a regulator is used to maintain the pressure to an optimum point.

According to the design in this study, the gas will be transported from the center of the dome as shown in Figure 13. Then, the gas will enter the burner through the pipe attached to the burner port as shown in Figure 14.

5. Conclusion

The demand for consumption of firewood during the injera baking process in the university cafeteria is very high due to the nature of the installed baking mechanism and the amount of injera baked. The daily average firewood consumption is 8600 kg which is equivalent to 790.3 m^3 of gas on a daily basis. This amount of firewood consumption is the main cause of deforestation leading to drought in the country. The installed injera baking mechanism in the cafeteria is a traditional three-stone fireplace that lacks an energy conservation mechanism and smoke outlet. The exhaust smoke generated in the injera baking process exposes women to a

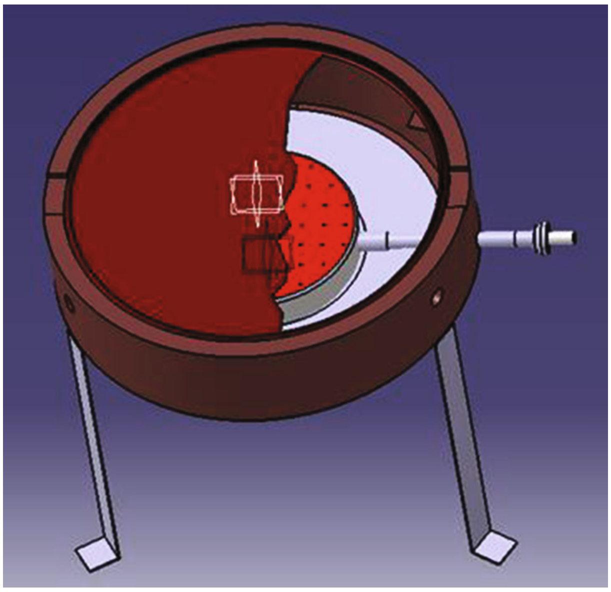

Figure 14: Biogas stove and burner.

serious health problem like lung cancer. So, to reduce the underlying issue stated, the biogas baking stove (mitad) is designed by integrating a biogas digester that yields methane from food waste.

In the study, the measured average daily biodegradable food waste and kitchen waste generation rate in the campus is around 863 kg/day; this kitchen and food wastes are disposed at the backyard of the cafeteria. The conversion of this food waste using the anaerobic digestion system yields 43.2 m^3 biogas per day. Utilizing the daily biogas generated for baking injera improves the overall food making process and reduces all the firewood consumption by 5.4%. In the study, a typical baking of mitad of 60 cm in diameter and efficiency of 25% requires an energy of 1.424 kW. The average mass of the dough is around 598 grams per each injera baked. An assessment made during baking states that the average time required to make injera is 120 seconds. The baking stove requires the energy of 1.424 kW; to maintain the energy demand required by the baking mitad, the biogas flow rate into the burner port is maintained at a rate of 0.93 m^3/hr. The biogas stove has 65 holes with 5 mm diameters opening adjusted at 90° to the vertical position which creates greater flame stability. The heat input for a given gas composition and supply pressure to the mitad is controlled by injector orifice. The designed biogas stove has no smoke generated due to the type of fuel used and configuration of baking mitad (stove). Furthermore, the stove has an insulation mechanism considered to conserve the heat loss to the surrounding. Generally, the utilization of the biogas system and integration of the biogas injera baking stove will improve the overall food processing mechanism in the university. A modification in burner port design could also improve the overall performance of the baking system by allowing a free discharge of fuel which still remains to be investigated in the future. However, the utilization of additional food waste from other cafeterias in the university will increase biogas generation and reduce firewood consumption in the country.

Data Availability

The data sets supporting the conclusion of this article are included within the article.

Conflicts of Interest

The authors declare that they have no competing interests.

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References

[1] K. D. Adem, D. A. Ambie, M. P. Arnavat, U. B. Henriksen, J. Ahrenfeldt, and T. P. Thomsen, "First *injera* baking biomass gasifier stove to reduce indoor air pollution, and fuel use," 2019, https://www.aimspress.com/fileOther/PDF/energy/energy-07-02-227.pdf.

[2] D. Kebede and A. Kiflu, "Design of biogas stove for injera baking application by GIZ and SNV non-governmental organization," *International Journal of Novel Research in Engineering and Science*, vol. 1, no. 1, pp. 6–21, 2014.

[3] K. Rajendran, S. Aslanzadeh, and M. J. Taherzadeh, "Household biogas digesters—a review," *Energies*, vol. 5, no. 8, pp. 2911–2942, 2012.

[4] G. Lissens, ,W. Verstraete, ,T. Albrecht,,,,, et al., "Advanced anaerobic bioconversion of lignocellulosic waste for bioregenerative life support following thermal water treatment and biodegradation by *Fibrobacter Succinogenes*," *Biodegradation*, vol. 15, no. 3, pp. 173–183, 2004.

[5] J. R. Surange, N. K. Patil, and ,A. V. Rajput, "Performance analysis of burners used in LPG cooking stove-a review," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 3, no. 4, 2014.

[6] J. Gregory, S. Silveira, A. Derrick, P. Cowley, C. Allinson, and O. Paish, *Financing Renewable Energy Projects, A Guide for Development Works*, Intermediate Technology Publications in Association with the Stockholm Environment Institute, 1997.

[7] S. Singh, ,S. Kumar, M. C. Jain, and D. Kumar, "Increased biogas production using microbial stimulants," *Bioresource Technology*, vol. 78, no. 3, pp. 313–316, 2001.

[8] M. Asmare, "Design of cylindrical fixed dome bio digester in the condominium houses for cooking purpose at Dibiza site, East Gojjam, Ethiopia," *American Journal of Energy Engineering*, vol. 2, no. 1, 2014.

[9] A. Nigatu and B. A. Gashe, "Effect of heat treatment on the antimicrobial properties of tef dough, injera, kocho and aradisame and the fate of selected pathogens," *World Journal of Microbiology and Biotechnology*, vol. 14, no. 1, pp. 63–69, 1997.

[10] J. W. Kang, C. M. Jeong, N. J. Kim, M. I. Kim, and H. N. Chang, "On-site removal of H_2S from biogas produced by food waste using an aerobic sludge biofilter for steam reforming processing," *Biotechnology and Bioprocess Engineering*, vol. 15, no. 3, pp. 505–511, 2010.

[11] Z. Ziauddin and P. Rajesh, "Production and analysis of biogas from kitchen wastevol. 2, no. 4, July 2015, https://www.irjet.net/archives/V2/i4/Irjet-v2i4109.pdf.