Journal of Engineering Science and Technology
Vol. 16, No. 6 (2021) 5071 - 5086

DESIGN AND ANALYTICAL STUDY FOR INFLUENCE OF THERMAL INSULATION ON ETHIOPIAN ELECTRIC INJERA BAKING PAN (MITAD)

FETENE TESHOME TEFERI[1], KISHOR PURUSHOTTAM KOLHE[2,*]

[1]Faculty of mechanical and industrial Engineering, Bahir Dar Institute of Technology-Bahir Dar University, Bahir Dar, P.O. Box 26, Ethiopia
[2]Faculty of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University, Ethiopia
*Corresponding Author: skishor75@gmail.com

Abstract

Electric Injera baking pan is the most dominant energy-intensive appliances used in Ethiopia. The major problems of existing electric Injera mitad are energy inefficient because of the high amount of electrical energy needed to heat up to the set temperature from 200 ºC to 250 ºC to bake Injera. The major factors for high energy requirement are poor heat insulation, high heat load to heat up, and fabrication method of electric mitad. However, in many available research study, efforts have been undertaking to improve the efficiency of Injera baking pan, but no satisfactory results have yet been reported. One of the major drawbacks of the available baking pan is heat loss in all directions of the top, bottom and sides of the body. The main objective of this research is to design and analytical study for the influence of thermal insulation on electric Injera backing pan, to make it more energy efficient by reducing energy losses caused by improper usage of insulation. In this study, the critical insulation thickness for electric mitad which has 58 cm from peripheral side and bottom direction is analysed as 0.32 cm and 7.2 cm respectively. The amount of heat that could be saved using critical insulation thickness is approximately computed as 833W per single mitad. Hence, there is also a possibility of annual saving 76,916,899.84 ETB by using appropriate thickness of fiber glass insulation. Finally, this study indicated that the insulation thickness should be considered during the manufacturing of mitad to reduce the heat loss, and a thermostat switch is preferably assembled to regulate the required temperature.

Keywords: Electric Injera mitad, Heat loss, Insulation, Performance efficiency, Power rate.

1. Introduction

Ethiopian Injera baking process comprises three basic steps. Initially, the baking clay pan should be heated with an appropriate temperature, and it should be polished at any food graded oil applicator to avoid sticking of Injera on the baking clay pan. Next, the batter commonly prepared from teff, or other cereals is quickly spread onto the flat baking pan by making a circular pattern on the baking pan starting from the center. Finally, after the Injera has baked with ample time, it is collected onto a flat cool pan and reserved on the common storage called Moseb.

The demand of indigenous electric Injera baking mitad in Ethiopia is increasing time to time because of the expansion of towns in the country. The lack of scientific study affects efficiency of Injera baking electric mitad, large amount of heat losses and unnecessary power cost on the users. The causes of the low energy efficiency of Electric mitad are the excessive heat loss from the set during operation, high heat loads, weight of clay plate, and lack of standards on the product, the traditional production methods, the limited research and innovation on the improvement of the product still now.

The clay plate of electric Injera mitad is made either as a single or double circular plate with having diameter ranging from 40 cm to 60 cm diameter and thickness of about 2 centimetres to 2.5 centimetres [1]. The clay plate which has 58 centimetres is demanded as an average size and assembled by Ethiopian mitad fabricators. The causes of energy inefficiency are mainly attributed to the high amount of electrical energy needed to heat up to the set to temperature about 200 ºC to 250 ºC required to bake Injera [1, 2]. However, the root causes of low energy efficiency of electric mitad are studied and predicted as heat load, heat losses, absence of standard on the size of Injera mitad, resistor quality and method of installation or assembly. Hence, electrical mitads currently produced in the country do not have equal and uniform power rating, even within the products of the same producer [2].

Measurements made at the premises of electrical Injera mitad producers during the survey; shows that the maximum initial power demand for most of the sets of 58 cm diameter ranges from 3.5 to 4.0 kW [2-4]. Moreover, the study has been attempted and made by the government, individuals, institutions and firms based in Ethiopia and abroad to improve the energy efficiency and production method of electric Injera mitad. The performance efficiency improvement studies made regarding electric Injera baking mitad are reviewed and presented below.

1.1. Power demand and consumption of mitad in Ethiopia

Electricity consumption of electric Injera mitad; depends on the power rating of the set, voltage level, thickness of the batter to be baked, and experience of the baker. There is no actual data on the number of electrical Injera mitad in Ethiopia. The present estimate is based on the data available with the Ethiopian Electric Utility (EEU) up to 2015. The measurements made at the premises of electrical Injera mitad producers during the survey showed that the maximum initial power demand for most of the sets of 58 cm diameter ranged from 3.75 to 4.0 kW. From the available literature, the steady state power demand for these is noted as 3.5 kW to 3.6 kW respectively [2-4]. The worst scenario shall be taken for estimation of demand; an average family size of five is estimated to bake Injera for two hours a day, ten days a month, thus bringing the average energy consumption to be 3.8 kW × 2 hr/day × 10 days per month is approximately 76 kWh per month [2, 4].

In the available literature, many researchers focused on finding alternative source of energy for Injera baking pan like; solar energy, biogas, steam and other sources. However, there is no significant study on reduction of heat loss and start up heat load on the clay Injera baking pan. Therefore; this gap in the literature is considered for the present research work.

The number of mitads and power growth is increase 10 per cent annually based on an average growth rate of Ethiopian Power system expansion master plan study for the high and low demand forecast of domestic customers, from year 2015 to 2024, as presented in Table 1 [2]. However; for a typical 58 cm diameter Injera mitad, the installed power demand in Ethiopia for year 2015 is estimated as 3.8 kW/ mitad × 583,000 mitad about 2,215 MW. Energy consumption in Ethiopia for year 2015 is estimated as 76 kWh/month per mitad × 583,000 mitads; approximately 44.3 GWh/month (531.7 GWh/year) [2].

From Table 1; it is observed that, in year 2015, the total installed power demand of the conventional 58 cm diameter electric Injera mitad is estimated to be 2.22GW. The energy consumption for the year 2015 is estimated to be 532 GWh. There is a huge power demand and energy consumption imposed on the electric generation and distribution infrastructure [4]. Recently, the Ethiopian Electric Power Corporation has tried to make label of electric Injera baking pans; to increase the competitiveness of manufacturers and to improve efficiency. In order to assign a labeling grade to the efficiency levels for different sizes of electric mitads, the energy efficiency index (R_I) of Injera mitads divided by the respective diameter of the mitad in meter. Table 2, depict the sample standard value of energy efficiency grade design for 58 cm diameter mitad.

Table 1. Forecasted power demand growth of electric Injera mitad scenario [2, 5].

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
NM	583,00	641,300	705,430	775,973	853,570	938,927	1,032,820	1,136102	1,249,712	1,374,683
IPD	2,215	2,437	2,681	2,949	3,244	3,568	3,925	4,317	4,749	5,224
EC	532	585	643	708	778	856	942	1036	1140	1254

NM = Number of mitads, IPD = Installed power demand (MW), EC = Energy Consumption (GWh)

From Table 2, the 3rd grade indicates that the mitad has energy efficiency index in between 1.34 and 1.51. Implementation of EE standards and labelling on electric Injera baking mitad would curb various constraints shown significantly by encouraging the development, marketing and sale of energy-efficient products. The saving on energy consumptions could be used for electrification of the rural areas, expansion of industries or sold to neighboring countries.

Table 2. Injera mitad EE labeling standard values by Energy Authority [2].

A	B	C	D	E	F	G	H	EE Index (RI)	EE Grade
3.8	912	3.8	912	100	50.0	0.58	0.86	<0.86	6
3.8	912	3.2	768	84.2	70.0	0.58	1.21	0.86 <RI <= 1.21	5
3.8	912	2.8	672	73.7	78.0	0.58	1.34	1.21 < RI <= 1.34	4
3.8	912	2.4	576	63.2	87.5	0.58	1.51	1.34 < RI <= 1.51	3
3.8	912	2.0	480	52.6	90.0	0.58	1.55	1.51 < RI <= 1.55	2
3.8	912	1.5	360	39.5	92.5	0.58	1.59	1.51 < RI <= 1.59	1

where : A = base power rating, B = base energy consumption (kWh) (assuming Energy consumption = 3.8 kW × 2 hr/day × 10 times per month ×12 months), C = Comparative power rating (kW), D = Comparative energy consumption (kWh) E = *per cent* comparative to base energy consumption, i.e. (D/B) in *per cent*, F = Efficiency assumed to correspond to (E), G = Injera mitad Diameter (meter), H = Energy Efficiency Index (RI), i.e., (F/G). According to EEPCo, the following parameters result should be shown on the labelling logo to aware manufactures and customers: Power rating (kW) = 220Volts (V) × Current (A)/1000, Annual energy consumption (kWh) = (Power rating (kW) × 2 hrs/day × 10 baking per month × 12 months), Annual energy cost of this product (Birr) is equal to annual energy consumption × annual operating hours, i.e., (Power rating (KW) × 2 hrs /day × 10 baking per month × 12 months) × (0.50 Birr/kWh) and CO_2 emission per year (tone CO_2) is equal to annual energy consumption (MWh) × Grid emission factor (about 0.0034 Ton CO_2/MWh for Ethiopia [2].

The labelling nameplate developed by EEPCo has 10 cm width and 7.5 cm length. The energy efficiency labelling logo comprises important information about the product. The common information shown on the logo are name of manufacturer, manufacturer model number, energy efficiency grade, diameter of clay mitad, power rating, annual energy consumption, annual energy cost, energy efficiency and CO_2 emission per year. At the bottom part of the nameplate, there is also a warning notice ‘removal of this label before first retail purchase is punishable by the law.’ which is declared by EEPCo. The energy efficiency labelling will have a positive impact for the development of improved energy efficient mitad by creating competition between researchers, technologists, and innovators.

1.2. Power demand and consumption of mitad in Ethiopia

Over 90% of energy consumed in household level in Ethiopia is for cooking and from this Injera baking accounts for 50-75% [6, 7]. Some researchers indicated that the traditional clay mitad have an estimated efficiency of 5-15% [7]. Others show that improved biomass stoves, have registered efficiencies in the range of 25-35% [8]. To tackle such challenges, many researchers have attempted to design and develop Injera baking alternatives like for example stoves based on biogas, solar power, and electricity [7, 8].

Fenta and Oquiño [9] have also studied on development and performance evaluation of electromagnetic induction Injera baking mitad. The prototype was constructed from Cast iron, Main Insulation - Ceramics and Working coil - enamelled copper wire. As per their test result, the average power consumption at full load and performance efficiency is 1.5 kW and 79.3 % respectively [9]. This result indicated that energy efficient Injera baking mitad will be fabricated with further detail scientific research works.

Electricity based mitad are a sound alternative and have become a popular alternative especially in the urban areas. However, their energy efficiency has to be improved drastically in order to prevent an overload on the electricity grid [8].

2. Methods and Materials

2.1. Methods

To conduct this research work, different methods are followed as presented below. Literatures are reviewed from journals, conference papers, bulletins, government reports and books.

Also, the existed electric Injera baking mitad is physically observed to identify the constraints of design and manufacturing techniques in Bahir Dar city, Ethiopia. Electric Injera baking mitad is indigenous technology in Ethiopia. It is fabricated by micro and small enterprises using simple hand tools and machineries. The body and its standard items are assembled by passing traditional routine process. The details of the geometry and physical features of the existed Injera baking pan is shown in Figs. 1(a)-(d).

After detail observation of the current electric mitad, improved conceptual design is developed. The conceptual design is also explored by using Auto CAD software for preparation of detail working drawing for further investigation and fabrication purpose (refer to *Appendix A*). Finally, analytical method is applied to estimate critical thermal insulation thickness for the reduction of electric power loss.

(a). Heating element embedded in clay.

(b). Mitad stand with resistor embedded clay.

(c) Sub-assembly of Injera baking mitad.

(d) Final assembly electric Injera baking mitad.

Fig. 1. Existed electric Injera baking pan features (a-d), (Photo captured in Bahir Dar, Ethiopia, October 2020).

2.2. Methods

Electric Injera baking mitad is fabricated in small and microenterprises in Ethiopia from structural steel like SHS, black sheet iron, aluminum sheet metal with assembling clay and heating element, temperature regulator switch, breaker, insulation materials, etc. [10-13]. These items are used as input to identify the existing limitation of electric Injera baking mitad. The preliminary design sketch of mitad is drawn by using Auto CAD 2009 software. Generally, literatures related to Electric mitad, existing mitad products, soft wares are used as an input to study and analyse the effect of insulation on Ethiopian electric Injera baking mitad.

3. Design and Analytical Study

3.1. Estimation of generated heat Energy of Injera baking mitad

The heat generated by the heating system is the input energy for Injera baking process. This input energy is estimated by using a function of voltage (V) and the resistance (R) flowing across the heating element. The amount of input power is computed by the following relation [1].

$$Q_{heat\ generated} = V^2 / R \tag{1}$$

Studies on resistance measurements made during the assessment in Ethiopia shows most resistors values ranging from 11.1 to 30 ohms; are in use for the mitads in Ethiopia [2]. Different length and resistance values are supplied by various suppliers. In addition, usual type of resistors, which are used by mitad assemblers' have values of 22.9 ohm, 23.1 ohm, 26 ohm, 28 ohm, and 30 ohms etc. The length and winded diameter of resistor are the basic factor for its ohm value. Table 3 shows the effect of resistance of heating element on the power generated and also presents the values found by computational analysis. The heating element, which has 11.1 ohm, 26 ohm and 30 ohm resistance, can generate 4360.36, 1861.54 and 1613.33 watt respectively. This indicates that the increasing resistance of the heating element decreases the generated electric power. The local manufactures of electric Injera baking mitad uses two heating elements (resistors) of 30 Ohms. This device can be operated using 220V alternative current from the main source. Hence; the possible heat energy that can be generated using these two resistors are estimated by using the relation: $P = V^2 / R$, where V= 220 V and R (heating element resistance =30 Ohms). Therefore, power generated using two resistors are used for the baking mitad, the total estimated energy that can be generated about 3227 W.

Table 3. Effect of resistance of heating element on input power.

Sample resistors (heating element)	Resistance value (Ω)	Electric Power generated (Watt) $P = V^2/R$, V=220 V	Power generated by Electric mitad using two heating elements (W)
1	11.1	4360.36	8721
2	12	4033.33	8067
3	15.4	3142.86	6286
4	22.9	2113.54	4227
5	26	1861.54	3723
6	28	1728.57	3457
7	30	1613.33	3227

3.2. Heat transfer and insulation

Heat transfer during baking with the use of a bake ware is based mainly on two processes of heat transfer, conduction, and convection mode of heat transfer. The heat transfer with conduction involves an interaction of molecules and atoms of nonmoving liquid or solid materials. Also transfer of heat with convection involves a solid and moving fluid with a differential temperature. The radiation mode of heat transfer process is usually being neglected, since the temperature achieved during cooking is still comparably moderate. Heat convection emerges between the bake ware top surface, the food stuff, like Injera, between the ambient air and outer surface of bake ware. Insulation is typically the largest resistance component in a heat loss system. The better the insulation resistance, the longer, it takes to reach thermal equilibrium. Factors, such as insulation type, thickness and operating temperature conditions affect overall insulation resistance [14, 15].

Table 4. Properties and selection of thermal insulation materials [16, 17].

No.	Type of insulation	Characteristics		
		Density (kg/m^3)	Thermal conductivity coefficient (W/m. K)	Maximum working temperature (°C)
1	**Glass fiber wool**	11 to 45	0.032 to 0.044	260 °C
2	**Rock wool**	30 to 200	0.035 to 0.039	750 °C
3	**Calcium Silicate**	220	0.06	650 °C
4	**Cera wool Blanket**	64 to 128	0.11	1260 °C

The insulations presented in Table 4, are commonly used for oven insulation. However, glass fiber wool is selected for this purpose because of availability and its appropriateness of working temperature. Glass fiber is the conventional material of choice for thermal insulation in appliances such as range cookers, ovens, and dual fuel cooking tops. It is predominantly used to prevent heat loss through conduction in electric, gas, and dual fuel models, to avoid heat transfer to the surrounding work surfaces. Fiber glass delivers better performance in less demanding cooking environments, providing acceptable levels of energy efficiency and safety. This performance is more than adequate for conventional cooking temperatures of 149 °C to 260 °C [18].

3.3. Estimation of critical insulation thickness

Critical insulation thickness is expressed as the thickness of thermal conductivity of insulation material divided by convective coefficient of heat transfer. The effective insulation thickness is computed using the following formulas [15].

$$T_1 = \frac{k}{h} \tag{2}$$

$$T_2 = \frac{1 - k}{h} \tag{3}$$

where, T_1 is critical side Insulation thickness, T_2 is critical bottom Insulation thickness, k is thermal conductivity coefficient of fiber glass insulation (k = 0.043 W/m.K), and $h$is convective coefficient of heat transfer (W/m^2K), $h = 5.7 + 3.8v$, where $v$is wind speed around Bahir Dar city, Ethiopia (2 m/s), $h = 5.7 + 3.8 * 2 = 13.3\ W/m^2K$.

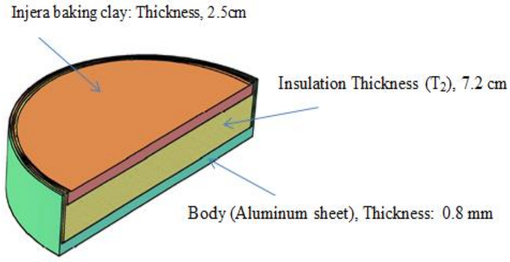
The critical insulation thicknesses T_1 and T_2 are obtained as follows using Eqs. (2) and (3):

$$T_1 = \frac{k}{h} = \frac{0.043\ \text{W/mK}}{13.3\ \text{W/m}^2\text{K}} = 0.32\ \text{cm}$$

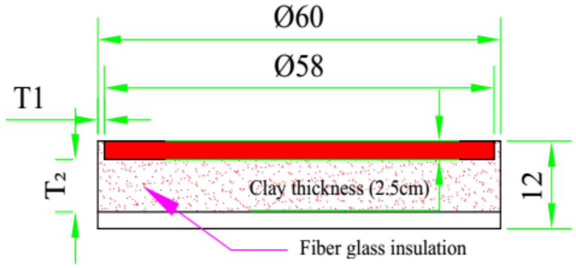
$$T_2 = \frac{1-k}{h} = \frac{1-0.043\ \text{W/mK}}{13.3\ \text{W/m}^2\text{K}} = 7.2\ \text{cm}$$

The critical insulation thicknesses value from side and bottom direction is computed as 0.0032 meter and 0.072 meter, respectively. As a result, the heat transfer with critical insulation thicknesses on electric Injera baking mitad is analyzed. Figure 2 depicts the optimal insulation thickness dimension from basic heat loss directions.

(a). Assembly of body, insulation, and baking clay.



(b). Half section view of Injera baking plate with its critical insulation thickness.



(c). dimensional Frontal sectional view of Injera baking mitad (T_1 = 0.32 cm and T_2 =7.2 cm)

Fig. 2. Critical insulation thickness from bottom and side of electric mitad (Source: sketched by Auto CAD 2009).

Heat transfer from bottom direction can be computed using the following relation.

$$Q_{bottom} = Q_{convection\ at\ bottom} + Q_{conduction\ at\ bottom} \quad (4)$$

$$Q_{bottom} = \frac{T^o_{clay} - T^o_{ambient}}{\frac{T_2}{kA_b} + \frac{1}{hA_b}} \quad (4.1)$$

where $A_b = \pi(r + T_1)^2$ or bottom surface area, r = radius of clay plate (mitad), T^o_{clay} = 250 °C or maximum temperature to bake Injera, and $T^o_{ambient}$ = 27 °C

The bottom surface area was calculated as the following:

$$A_b = \pi(r + T_1)^2 = \pi(29\ \text{cm} + 0.32\ \text{cm})^2 \cong 0.27\ \text{m}^2$$

Now, the heat transfer from bottom direction was obtained using equation (4.1)

$$Q_{bottom} = \left(\frac{250 - 27}{\frac{0.072}{0.043 * 0.27} + \frac{1}{13.3 * 0.27}} \right) W = 34.41W$$

Heat transfer from side direction, Q_{side}

$$Q\_side \;=\; Q\_(convection\ at\ side\ +)\ Q\_(conduction\ at\ side\ ) \quad (5)$$

$$Q_{side} = \frac{T^{o}_{clay} - T^{o}_{ambient}}{\left(\frac{ln\left(\frac{r+T_1}{r}\right)}{2\pi k t_{clay}} \right) + \frac{1}{hA_O}} \quad (5.1)$$

where, $A_o = 2\pi(r + T_1)t_{clay}$ or surface area, and its value was obtained as

$A_o = 2\pi(0.29 + 0.0032) * 0.025\ \text{m}^2 = 0.046\ \text{m}^2$

Now, the heat transfer from side direction was obtained using Eq. (5.1)

$$Q_{side} = \frac{250 - 27}{\left(\frac{\ln\left(\frac{0.29 + 0.0032}{0.29}\right)}{2 * 3.14 * 0.043 * 0.025} \right) + \frac{1}{13.3 \times 0.046}} = 68.76\ \text{W}$$

The total heat loss with insulation was found as

$$Q_{loss\ with\ insulation} = Q_{convection\ from\ bottom} + Q_{convection\ from\ side} = 34.41\ \text{W} + 68.76\ \text{W} = 103.17\ \text{W}$$

Heat transfer without insulation on electric Injera baking mitad:

Heat transfer from side direction without insulation from the side

It was also determined using Eq. (6) as shown below:

$$Q_{convection\ from\ side} = 2h\pi r(T^{o}_{clay} - T^{o}_{ambient})t_{clay} \quad (6)$$

$$Q_{convection\ from\ side} = 2 \times 13.3 \times 3.14 \times 0.29 \times (250 - 27) * 0.025\ \text{W} = 135.04\ \text{W}$$

Heat transfer from side direction without insulation from the bottom

It was also determined using Eq. (7) as shown below:

$$Q_{convection\ from\ bottom} = hA_b(T^{o}_{clay} - T^{o}_{ambient}) \quad (7)$$

$$Q_{convection\ from\ bottom} = 13.3 \times 0.27 \times 0.29 \times (250 - 27) = 800.8\ \text{W}$$

The total heat loss without insulation was found as

$$Q_{loss\ without\ insulation} = Q_{convection\ from\ bottom} + Q_{convection\ from\ side} = 800.8\ \text{W} + 135.04\ \text{W} = 935.84\ \text{W}$$

The amount of heat that could be saved using insulation was found as follow:

$$Q_{saving} = Q_{loss\ without\ insulation} - Q_{loss\ with\ insulation} = 935.84\ \text{W} - 103.17\ \text{W} = 832.67\ \text{W}$$

The analytical result shows that there is a possibility to save 0.83267 kW × 2 hours per baking Injera × 10 days per month × 12 months (199.84 kWh) heat energy per annum from a single mitad by using appropriate insulation materials from bottom and peripheral side of a 58 centimeter diameter electric mitad.

From Table 1, the forecasted number of electric mitad in 2020 is about 938,927. It means that Ethiopia may save gross amount 93,817,585.84 ETB (938927 mitads × 199.84 kWh per annum × 0.5 Birr/kWh) annually with in this scenario. The average current price of fiber glass which has density 11 kg/m^3 used by electric mitad assemblers in Ethiopia is about 80 ETB per kilogram. The amount of fiber glass insulation used for a single mitad is about 0.02 m^3 volumes or 220 gram which costs approximately 18 ETB. The total cost of fiber glass insulation at national level for the number of mitad 938,927 in 2020 is about 16,900,686 ETB per annum. This analysis indicates that there is a possibility to save 76,916,899.84 ETB of money per annum at national level using appropriate thickness of insulation.

3.4. Estimation of thermal efficiency

In this study, the thermal efficiency of electric Injera baking mitad is estimated only considering heat losses from the peripheral side and bottom of the mitad body. The thermal efficiency can also be estimated by using the following formula [17].

$$\text{Thermal efficiency} = \frac{Q_{net\ heat\ utilized}}{Q_{input\ heat\ generetaed}} \tag{8}$$

$$Q_{net\ heat\ utilized} = (Q_{heat\ generated} - Q_{total\ heat\ dissipated}) / Q_{heat\ generated} \tag{8.1}$$

Table 5 represents the analytical analysis calculated by taking corresponding temperatures and insulation thickness on the redesigned electric Injera baking mitad with increasing thickness of fiber glass insulation around it. It is revealed from the table that heat dissipation decreases with increase in the insulation thickness.

Table 5. Analysis summary result of heat transfer for Injera baking mitad (watt).

Insulation sample	Sample Insulation Thickness (cm)	Heat generated (Q)	Heat dissipated (Q bottom)	Heat dissipated (Q side)	Total heat Dissipated (Q loss)	Efficiency (%)
1	0	3227	800.79	135.0	935.83	71.00
2	0.32	3227	402.26	95.15	497.41	84.59
3	1	3227	195.65	42.17	237.82	92.63
4	2	3227	111.44	22.25	133.69	95.86
5	3	3227	77.91	15.31	93.22	97.11
6	4	3227	59.89	11.66	71.55	97.78
7	5	3227	48.64	9.52	58.16	98.20
8	6	3227	40.94	8.04	48.98	98.48
9	7.2	3227	34.41	6.83	41.24	98.72
10	8	3227	31.11	6.21	37.32	98.84
11	9	3227	27.77	5.61	33.38	98.97
12	10	3227	25.08	5.11	30.19	99.06

4. Results and Discussion

The analytical results of requirement of insulation and effect of size of heating element on power generation are presented graphically as shown on Figs. 3 and 4.

Figure 3 depicts that increasing resistivity of heating element has an effect for reduction of input power. The nickel-chromium resistance wire is suitable for heating elements used for temperatures up to 1200°C. This is used for electrical cooking equipment like Injera baking mitad. It is nominally composed of 80 percent nickel and 20 percent chromium. The resistivity of the heater wire is varied because of the variation of composition of its alloying element. Two heating wires which have 30 ohm resistance are commonly used to generate 3227 watt energy for Injera baking mitad. Lack of knowledge on the resistivity and composition of the heating element leads the manufacturer to use improper heating wire that will not generate the required heat energy.

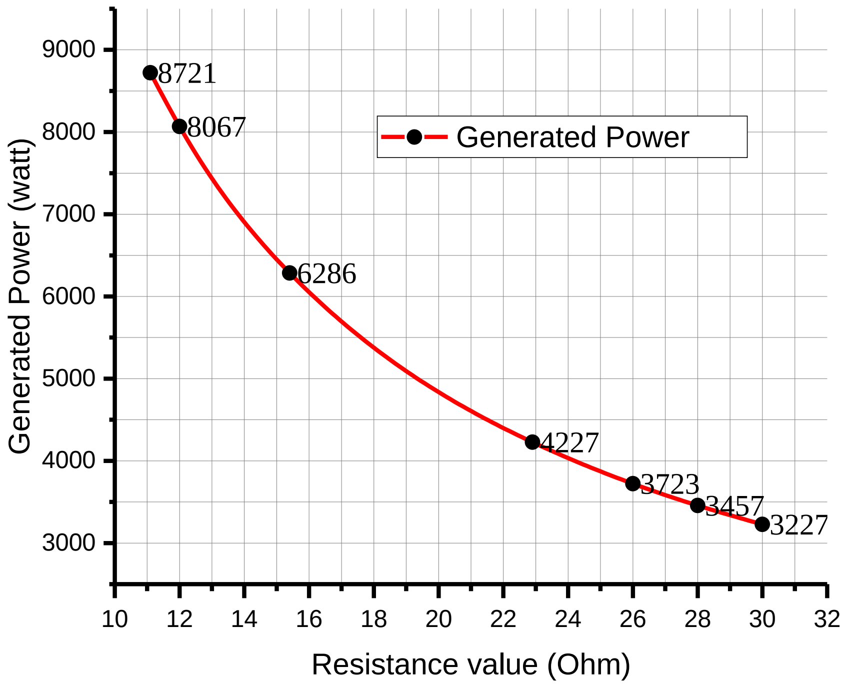


Fig. 3. Resistance of heating element versus input power.

Figure 4 illustrates the comparative graph of heat loss reduced while increasing the thickness of insulation. However, the optimal insulation thickness should be applied to maintain energy loss and unnecessary costs. Also, the efficiency of electric mitad is increased while insulation thickness is increased.

The current selling price of fiber glass insulation for Injera baking mitad is approximately 80 ETB in local market. As per analytical analysis a single mitad consumes 220 gram insulation which costs 18 ETB. Using much more quantity than critical insulation thicknesses lead the manufacturer for unwanted costs. The maximum energy efficiency of the Injera baking pan was 98.72 per cent which can be achieved by using 7.2 cm insulation thickness from the bottom direction.

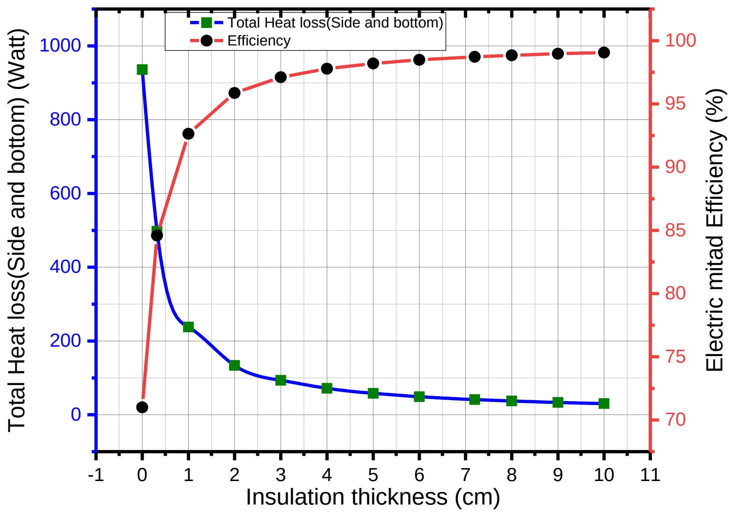


Fig.4. Insulation thickness versus heat loss.
(Source: sketched by Origin 2017)

5. Conclusions

The existing electric mitad has many limitations from design and manufacturing perspective that leads to high dissipation of energy during Injera baking. It is also varied in their performance and quality from producer to producer. The basic reasons for their differences are due to lack of scientific research work on the design of mitad, materials type, and manufacturing techniques. From this study, the following conclusions are drawn.

- According to Ethiopian electric utility data, the number of mitad and demand of electric power is increased by a minimum of 10 per cent in every year.
- Because of lack of standardization of electric mitad, large amount of loss of power are observed which means that the mitad manufacturer in the country have not used standard heating element, clay thickness and insulation materials and thickness.
- The analytical study shows that with increasing the thickness of insulation, the dissipation of heat reduces and efficiency of the mitad is improved.
- The purpose of insulation is to reduce the total unwanted heat dissipation. Hence, the optimum thickness of insulation should be greater than critical thickness of insulation. However, providing greater insulation thickness is not economically viable due to its high cost.
- The critical insulation thickness value for electric mitad which has 58 cm from peripheral side and bottom direction is analyzed as 0.32 cm and 7.2 cm respectively. Hence the electric mitad assemblers should apply a minimum of these thicknesses to reduce the heat loss. In addition, the performance efficiency of electric mitad can be improved by using low resistant heating element, minimum weight baking clay and by assembling thermostat switch to regulate the temperature required for Injera baking.

- The analytical study shows that there is a possibility to save 199.84 kWh heat energy per annum from a single mitad by using appropriate insulation materials, while applying from bottom and peripheral side of a 58 centimeters diameter of electric mitad. Considering the total number of mitad in 2020, the total money saving is also approximately 76,916,899.84 ETB per annum at national level using appropriate thickness of insulation.

6. Future scope

This research was focused on analytical study for influence of thermal insulation on Ethiopian electric Injera baking pan. In future research works, heat transfer simulation should be studied on Injera baking mitad and insulation materials for heat loss reduction purpose. In addition, thermal conductivity improvement on the clay part of mitad is required to minimize the startup heat load and saving of electric energy.

Nomenclatures

I	Current, A
Q	Heat transfer, W/m.K
R	Heating element resistance, Ω
R_I	Efficiency index
T_1	Critical side Insulation thickness, cm
T_2	Critical bottom Insulation thickness, cm
V	Voltage, V

Abbreviations

EE	Energy Efficiency
EEPCo	Ethiopian Electric Power Corporation
EEU	Ethiopian Energy Utility

References

1. Mulugeta, B.; Demissie, S.W.; and Nega, D.T. (2017). Design, optimization and CFD simulation of improved biogas burner for ‘Injera’ baking in Ethiopia. *International Journal of Engineering Research &Technology*, 6(1), 58-64.
2. DANAS Electrical Engineering (2015). Project document on electric Injera mitad: Energy efficiency standards and labeling, 12-24.
3. EEPC. (2014). Ethiopian power system expansion master plan study. *Final Report*, (2): *Load Forecast Report & Distributed Load Forecast Report*. Prepared for Ethiopian Electric Power Corporation (EEPC), Ethiopian Electric Utility Consumption Data.
4. MoFED. (2014). Growth and transformation plan: *Annual Progress Report for F.Y.* 2012/13. Ministry of Finance and Economic Development (MoFED), Federal Democratic Republic of Ethiopia, 50-52.
5. Tafere, A.T (2011). *Experimental investigation on performance characteristics and efficiency of electric injera baking pans* (*Mitad*). Master Thesis, Addis Ababa University School of Graduate Studies Institute of Technology Energy, Addis Ababa, Ethiopia.

6. Kebede, D.; and Kiflu, A. (2014). Design of biogas stove for injera baking application. *International Journal of Novel Research in Engineering and Science*, 1(1), 6-21.
7. Tesfay, A.H.; Kahsay, M.B.; and Nydal, O.J. (2014). Solar powered heat storage for injera baking in Ethiopia. *Energy Procedia*, 57, 1603-1612.
8. Jones, R.; Diehl, J.C.; Simons, L.; and Verwaal, M. (2017). The development of an energy efficient electric Mitad for baking injeras in Ethiopia. *Proceedings of the* 25*th International Conference on the Domestic Use of Energy: Towards Sustainable Energy Solutions for the Developing World*. Cape Town, South Africa, 75-82.
9. Fenta, F.; and Oquiño, V.H. (2019). Design and development of Electromagnetic induction injera Mitad. *International Research Journal of Engineering and Technology* (*IRJET*), 6(5), 12-17.
10. Teshome, F.; Messele, E.; and Kolhe, K.P. (2019). Development and testing of improved double skirt rocket stove for reducing emission level of carbon monoxide, *ICAST* 2019 *Springer*, 537-547.
11. Kolhe, K.P.; and Datta C.K. (2007). Prediction of microstructure and mechanical properties of multipass SAW. *Journal of Material Processing Technology*, 197(1-3), 241- 249.
12. Kolhe K.P. (2015). Testing of tractor mounted and self propelled coconut climber for coconut harvesting. *World Journal of Engineering*, 12(4), 399-406.
13. Kolhe K.P. (2015). Stability analysis of tractor mounted hydraulic elevator for horticultural orchards. *World Journal of Engineering*, 12 (5), 479-488.
14. Hart, G.H.; and Whitaker, T. (2008). Insulation materials: Calcium silicate block and pipe. Retrieved September 1, 2008, from https://insulation.org/io/articles/insulation-materials-calcium-silicate-block-and-pipe/.
15. Tiwari G.N., Tiwari A., Shyam (2016) Evacuated tubular solar collector (ETSC). In: Handbook of solar energy. energy systems in electrical engineering. Springer, Singapore, 310-320.
16. Dunster, A.M. (2007). Industrial sector study on the utilization of alternative materials in the manufacture of mineral wool insulation. Retrieved September 1, 2008, from http://sciencesearch.defra.gov.uk/Document.aspx?Document=WR0115_8432_FRA.pdf
17. Hailu, M.H.; Kahsay, M.B.; Tesfay, A.H.; and Dawud, O.I. (2017). Energy consumption performance analysis of electrical mitad at Mekelle City, *Momona Ethiopian Journal of Science* (*MEJS*), 9(1), 43-65.
18. Dixit, N.; Mantri, R.; Aranke, O.; and Godbole, A. (2016). Effect of thermal insulation on thermal efficiency of portable solid biomass cook stove. *International Journal of Innovative Research in Science*, *Engineering and Technology*, 5(4), 4665-4672.

Appendix A

Working drawing of redesigned electric Injera Baking pan (mitad).

The major parts of electric Injera baking mitad are stand, baking element and led. The shape and size of these parts were drawn and explored using Auto Cad 2009 software as shown below on the figures.

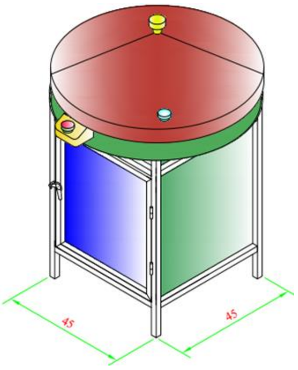


Fig. A-1. 3D drawing of electric Injera baking mitad.

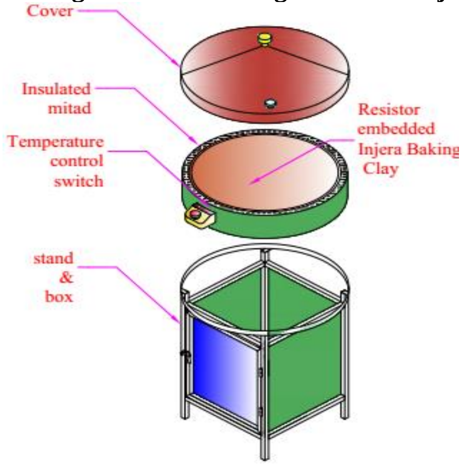


Fig. A-2. Exploded drawing of electric Injera baking mitad.

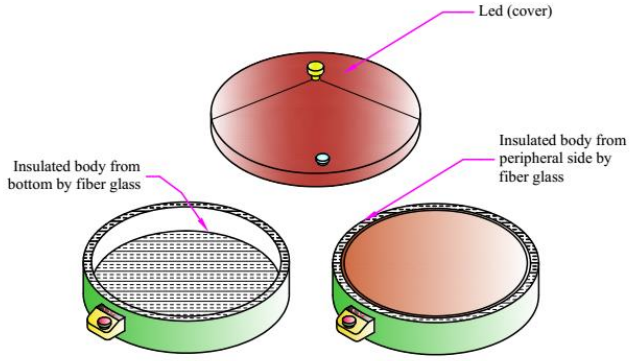


Fig. A-3. Insulated subassembly Injera baking mitad.

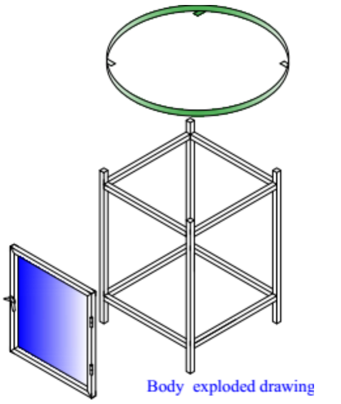


Fig. A-4. Exploded drawing of electric mitad body.

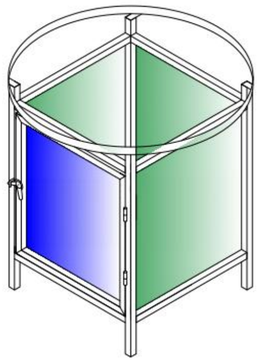


Fig. A-5. Assembled drawing of electric mitad body.

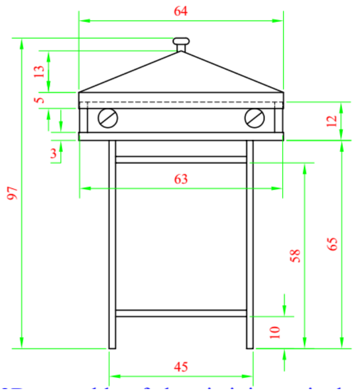


Fig. A-6. Dimensioal drawing of frontal view of electric mitad.

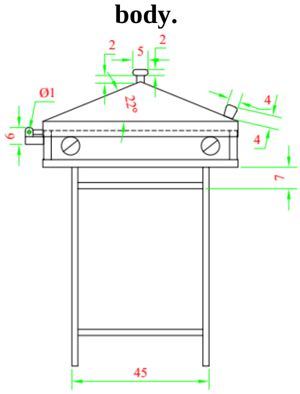


Fig. A-7. Dimensional drawing of side view of electric mitad.

Note: All units are given in centimeter unless specified.