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Design and development of Electromagnetic Induction Injera Mitad

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Abstract *– Injera is the basic food for Ethiopian people. Ethiopian injera food item is very sensitive to environment and process of baking. Depending on the grain type, batter viscosity and other conditions, injera baking requires temperature ranging from 150°C to 180°C. To generate this temperature, the locally manufactured traditional electric injera mitad uses Nickel–Chrome resistive heater as heat source. The locally manufactured electric injera mitad consumes 3 – 3.5 KW power. In addition, it has excessive heat loss and consequently low efficiency. Electromagnetic injera mitad (EMIM) prototype was developed to improve these limitations. EMIM uses basic law of electromagnetic induction for its operation. The output power is controlled by controlling switching frequency of the resonant inverter. A series of lab and field tests were conducted and finally, EMIM performance parameters such as consumed power, efficiency, initial heating-up time, and quality of injera (its texture and softness) were compared with traditional electric injera mitad performances. The test result showed that, for a similar injera quality, the power consumption was reduced to 50%, the initial heating up time was reduced to 48%, and the efficiency was increased around 34%.*

Key words: - working coil, magnetic field, resonant inverter, cast iron, eddy current, Injera, Mitad.

1. INTRODUCTION

Injera is bread like staple food of most Ethiopians, especially in central and northern parts of the country. By its very nature, a good and acceptable injera is thin, soft and has distinctive texture with bubbly eyes and appearance. Injera baking is done by a device or apparatus named *injera mitad* (plate used to bake injera) manufactured from special clay. The widely used traditional way of injera baking (three stones and open fire) uses biomass products like wood, animals dung & agricultural crop residues as heat source. It resulted in depletion of resources, degradation of local environment and much time is expended to collect for daily consumption. It also creates indoor air pollution during baking that causes health problems. In addition to biomass energy sources, it is estimated that, 77% urban dwellers (those with direct access to electricity) use electrical energy for injera baking [5]. The locally manufactured conventional electric injera mitad which is used for decades has resistive heater as heat source.

In addition to high accumulation of heat energy in the clay, it has excessive heat losses through different parts. The majority of existing electric injera mitad power rating is around 3.0 – 3.5 KW [5]. Thus, it is energy intensive product and its efficiency is as low as around 45% - 55%. [1]. Improving efficiency of electric injera mitad will reduce demand power and save energy; encourage research and innovation, etc.

It was roughly estimated in 2007 that, nationally around 530,000[8] locally manufactured electric injera mitades were in use. Because of rapidly growing energy demand and shift from biomass to electricity in urban areas, in 2018 this number is roughly projected to be doubled whereas the major limitations do still exist.

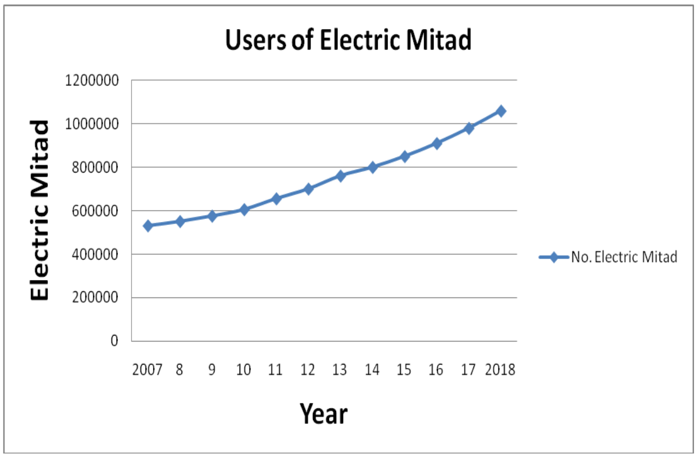

Chart -1: Number of Injera Mitad Projected

The projected number of locally made electric mitad per year was shown in chart 1. This was calculated based on the number of individuals and families that uses the electric mitad for baking the injera. The basis of this projection was based on 2007 recorded number of users and the number of registered electric mitad. Since injera was the basic food for all Ethiopian people, it was expected that more families and individuals were going to use electric mitad. Based from the data gathered at the end of 2018, there were 1,060,000 electric mitad that were used all over the country. And by the end of 2019 it was expected to increase up to 50% of electric mitad that will be circulating in the country.

Using this type of mitad for baking injera requires more power consumption. Along with this power requirement of locally made electric mitad, power losses on the part of country's power economy will also be affected due to this rapidly increasing this type of mitad that the people were using.

Table1. Locally manufactured electric mitad data

No	Description	Unit of M.	Avg. Value
1	Applied Voltage	V	220
2	Current	A	16
3	Consumed power	KW	3.22
4	Working temperature	^oC	170
5	Initial heating up time	min	17.48
6	One injera baking time	min	1.76
7	Power factor	-	1.0
8	Efficiency	%	45

The specification of locally made electric mitad was shown in table1. This table was taken based on the averaged 13 locally manufactured electric mitad around the place. Based on the data in table 1, the average power consumption of the locally available electric mitad was 3.22 kW with efficiency of 45 percent. The initial heating up time was the preparation time for the machine to bake the injera. In the locally made electric mitad it was found out to be almost 18 minutes before the machine be ready for cooking injera.

1.1 Problem Statement

Baking injera was made 2 -3 times a week by each household. Due to its high power consumption and low efficiency, the locally manufactured electric injera mitad is energy intensive device and consumes around 60% –70 % [14] of the total household energy requirement.

Based on the specification of locally made electric mitad, the power consumption was very high. It was known that the energy consumption was the product of time and the power consumed by the machine. In order to reduce the energy consumption of the machine for baking injera, the efficiency and the initial heating up time should also be reduce. Increasing the efficiency of the machine reduces the power losses of the machine.

Likewise reducing its power consumption and increasing its efficiency will definitely result in remarkable national energy savings and significant reduction in consumer's expenses for energy usage.

1.2 Objectives

The main objective of this research study was to design and develop injera mitad prototype with improved efficiency and power consumption as compared with the locally made electric mitad for cooking injera in Ethiopia.

2. MATERIALS AND METHOD

The design and development of injera mitad may vary based on the availability of different materials. The design procedures in this work were based on the availability of materials and components in the country. In addition, to design and develop efficient injera mitad, a thorough understanding of the entire injera baking process like fermenting under controlled environment, proper viscosity of batter, precise control of cooking temperature, are required.

2.1 Operating principle of Electromagnetic induction injera mitad

Induction heating is the process of heating electrically conductive materials by a process called electromagnetic induction. One of the many applications of induction heating is cooking.

Figure 1 shows the general block diagram of the system. AC voltage is converted to DC and applied to a high frequency converter. High frequency current is made to flow in the planar coil (supposed to be primary) which generates high frequency magnetic field. The high frequency magnetic field couples the work piece (cast iron - supposed to be secondary).

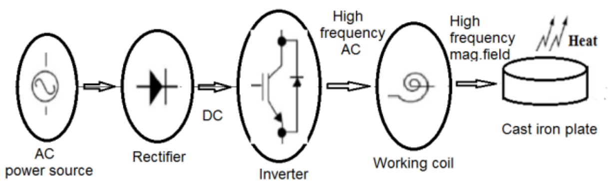

Fig – 1 : General Block diagram of the system

According to Faraday's law, a time dependent magnetic field through a closed curve induces an electromotive force (emf) around the curve which causes eddy current flow in it.

$$E_{ind} = \oint \vec{E}.d\vec{s} = \int_{area} \vec{\nabla} \times \vec{E}.d\vec{A} = -\frac{\partial}{\partial t} \int_{area} \vec{B}.dA = -\frac{\partial \phi_B}{\partial t}$$

$$E_{ind} = -\frac{\partial \phi_B}{\partial t} = -N\frac{\partial \phi_B}{\partial t}$$

$$P = \frac{E^2}{R} = i_{eddy}{}^2 R$$

where, R – ohmic resistance

The amount of heat dissipated depends on the frequency of the eddy current, magnetic field density and thickness of the cast iron work piece. In addition to eddy current, there is small contribution of hysteresis effect.

$$P = P_{iron} = P_e + P_h$$

Where, $P_e = K_e f^2 B_m^2 t$ is Eddy current loss

$P_h = K_h f B_m^x$ Hysteresis loss

f – Operating frequency

B_m^x – max. flux density

x – Steimetz constant

t – Thickness of the work piece (iron)

K_e, K_h – constants of material type.

2.2 Selected Materials and parameters

Work piece – Cast iron
Main Insulation– Ceramics
Working coil – enameled copper wire
Working temperature - 160°C– 180°C
Supply voltage – 220 V, 50 Hz
Operating frequency – 24 KHz - 30 KHz
Design power – 1.2 KW - 1.5 KW
Control and protection system – MCU with sensors

2.3 Design considerations of main components

Working coil – The specification of the manufactured working coil is given below. Its number of turns, inter-turn spacing and total diameter is dependent on the diameter and manufacturing perfection of accommodating ceramic insulator.

Table -1: Induction Coil Design Requirement

No	Description	Symbol	Value
1	Diameter of a strand	D_s	0.72 mm
2	Cross-sectional area of a strand	A_s	0.41 mm²
3	Number of stands in parallel	a_s	20 strands
4	Diameter of the bundle	D_b	4 mm
5	Cross-section of the bundle	A_b	8.0 mm
6	Number of turns of the coil	N	32 turns
7	Total length of the coil	l_c	23 m
8	Outer diameter of the coil	D_{out}	440 mm
9	Inner diameter of the coil	D_{in}	30 mm
10	Average radius of the coil	r_{avg}	110 mm
11	Inter-turn space	S	2.5 mm
12	Depth of the coil	W	205 mm
13	Height of the coil	Hc	4 mm

Cast iron - due to its peculiar magnetic and thermal characteristics cast iron is selected to replace clay with embedded resistor. Its surface is carefully seasoned with flax seed oil and Polytetrafluoroethylene (PTFE) to make nonstick and corrosion free.

Table -2: Cast iron design requirements

No	Description	Symbol	Value
1	Density	Υ_w	7150 kg/m³
2	Relative permeability	μ_{rw}	250
3	Resistivity(20°C)	ρ_w	9.61 x 10^{-8}Ω.m
4	Specific heat capacity	c_w	460 J/Kg. °C
5	Thermal conductivity	λ_w	50 W/m.K
6	Diameter	D_w	0.45 m
7	Thickness	h_w	0.005 m

Inverter - Single switch load resonated ZCS inverter module of 1.8 KW was used as switching device due to its simplicity, low cost and better performance. The frequency is varied from 24 KHz up to 30 KHz to achieve different power levels by selector push button switch.

2.4 Structural arrangement of the EMIM prototype

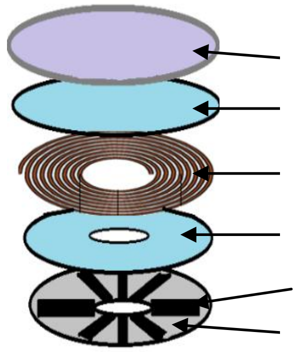

Fig – 2 : EMIM Construction Arrangement

Figure 2 shows the arrangement of the core component of the induction injera mitad. The size of cast iron was selected based on the required size of injera. The ceramic was used as thermal insulator from the cast iron generated heat. At the next layer was the coil driven by high frequency pulses to generate heat in the cast iron. At the bottom layer a magnetic material was place to complete the flow of electromagnetic flux in the system.

3. RESULTS AND DISCUSSION

A series of laboratory and field tests were conducted to verify the performance of the developed prototype with the set objectives. Table 3 shows summary of the test results.

The total energy loss in the form of heat was : -

Total loss = total top loss + total bottom loss + total loss at sides + losses in electrical components.

$$Q_{T.loss} = Q_{.top} + Q_{.bottom} + Q_{side} + Q_{elec}$$

$$Q_{T.loss} = 117.4 + 163.66 + 13.06 + 15.9 = 310.02\ watt$$

$$\eta = \frac{P_{in} - p_{loss}}{P_{in}} = \frac{1500 - 310.02}{1500} = \frac{1189.98}{1500} = 79.3\%$$

where, P_{in} – input power, [watt]

P_{loss} – total loss in the system, [watt]

$P_{out} = P_{in} - P_{loss}$

Since the operating principles of EMIM was similar to that of a transformer, apparent power in the working coil (primary) was equal to apparent power in the work piece (secondary).

$$V_1 I_1 \approx V_2 I_2 \Leftrightarrow S_1 = S_2$$

Where; $S_1 = S_2$ – apparent power. [KVA]

Thus, operating power factor,

$$Cos\varphi_2 = \frac{P_{out}}{S} = \frac{P_{out}}{V_2 \times I_2} =$$

$$= \frac{P_{out}}{V_1 \times I_1} = \frac{1189.98}{220 \times 7.6} = 0.71$$

Table -3: Test Results

No	Parameters description	Average value
1	Average Room temperature	20°C
2	Input voltage (regulated)	220 V
3	Input current	7.64 A
4	Input power	1.50 KW
5	Work piece temperature range	117°C – 130°C
6	Heating up time (130°C displayed)	8.5 min
7	Average bottom temperature	68°C
8	Average side temperature	40°C
9	Average lid temperature	30°C
10	Time taken to bake one injera	1.32 - 1.42 min

The following table 4 shows parameters of EMIM compared with that of conventional electric mitad.

Table 4 – Table of comparison

No.	Indicators	Electric Mitad	EMIM	Remarks
1	Average Initial heating time	16 - 18 min	7 – 9 min	50% improved
2	Average consumed Power at full load	3.2 – 4.00 KW	1.50 KW	50% improved
3	Efficiency	45 – 55 %	79.3%	24% improved
4	Power factor	-	0.71	-
5	Injera texture	V. good	V. good	Comparable

The results showed in table 4 were further confirmed by some experts during the turn over presentation to the research park in Adama Science and Technology University, Ethiopia.

The actual output power is 1.189.98 KW. Then, energy consumed will be:

$$E = P_{out} \times t = Q = m_w c_w (T_f - T_{in}),\ joules$$

The final injera baking temperature was taken to be 180°C and the room temperature is 20°C.Thus, the initial heating time required to bring the work piece to 180°C was:

$$t = \frac{m_w c_w \Delta T}{P_{out} \times 60} = \frac{5690 \times 0.460 \times 180}{1189.98 \times 60} = 6.59\ \text{min}$$

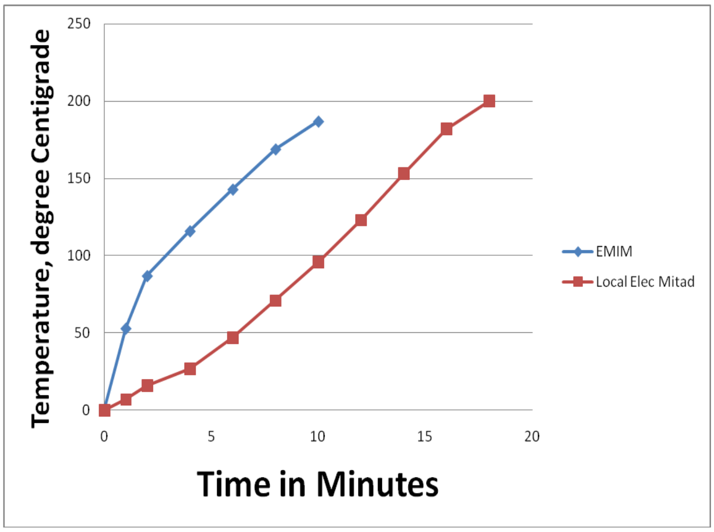

Chart -2: Initial Heating up Time of EMIM vs Local Electric Mitad

The comparison of the initial heating for the preparation of baking injera was show in chart 2. It was observed that the developed induction injera mitad was faster in producing heat as compared with the locally made electric mitad available in the country.

The above chart indicates that the initial heating up time was almost half of that of local electric mitad.

The assembled prototype of induction injera mitad was designed with LCD display which was used to display the temperature of the iron core.

Fig – 3 : Developed and assembled EMIM prototype

The user can view the temperature to determine the right temperature for cooking injera. The power for the heating of the iron core can be selected using the push button switch which can be found near the LCD display panel. The circuit breaker was also used against faults and over current protection in order to be safe..

In order to get a good quality injera, it was tested that the temperature scale on the LCD display must reach 117 °C for one day fermented injera batter and 130°C for more than one day fermented batter. The microcontroller controls the temperature in the ranges of minimum of 130°C and maximum temperature of 140°C.

Fig – 4 : The Output Injera

Figure 4 shows the cooked injera by induction injera mitad. The cooked injera was tested and evaluated by some experts during field test. It was found out that the EMIM cooked injera had acceptable quality.

3. CONCLUSIONS

Injera will continue to be the staple food of Ethiopians years to come. Currently, biomass is the dominant source of energy used for injera baking followed by electricity. As seen in different literatures, energy consumption of existing traditional electric mitad is around 60 % - 70% of the total household demand which initiates research and development work for improved injera baking system.

The developed induction injera mitad was highly appreciated and accepted by the experts and some injera consumers. As compared with the existing injera mitad, it was concluded that Ethiopian injera with its beautiful texture and flavor can be baked by EMIM using cast iron work piece provided that the cast iron surface must be well seasoned (treated) to obtain nonstick surface. The Mitad temperature must be carefully controlled within ± 5% of working temperature. Compared with locally manufactured electric injera mitad, the developed induction injera mitad has lower initial heating up time and improved efficiency leading to lower power consumption.

There were different families of metals were tested for the base and casing of the machine. There were also metals that give better results than others. It was concluded that cast iron performs better than the others for the base of the machine. Aluminum materials were used for shielding along with the top cover. Through this the developed induction injera mitad successfully baked a good quality injera for the people of Ethiopia.

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BIOGRAPHIES

Feleke Fanta M. received advanced diploma in electrical technology from Bahidar Polytechnic Institute, Ethiopia. Following graduation, he worked as electrician in Ethiopian Fabrics textile factory, Asmara. He studied his BSc & MSc in Electromechanical Engineering at Zaparodje Machine Building Institute, Ukraine. Following MSc graduation in 1990, he worked in different factories and government offices till 2004. Since September 2004, he has been lecturer in Adama Science and Technology in electrical power and control engineering department. His research interest includes Electrical machines and power electronics and electrical control system.

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