ENERGY CONSUMPTION IN BREAD BAKING

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ABSTRACT

The main aim of the present work is to study and evaluate energy consumption in bread baking. This was achieved by determining the energy consumed in each stage of bread baking processing to assess the most consumable stage of bread baking process. Magr baladi, Mawi and French bread baking were evaluated processes. Thermal, electrical and human energy sources were determined. The results indicated that the total specific energy consumed were 3038.11, 2831.85 and 4823.53 kJ kg^{-1} for magr baladi bread, mawi baladi bread and French bread, respectively. The specific electrical energy consumed were 42.21, 40.33 and 59.92 kJ kg^{-1} for magr baladi bread, mawi baladi bread and French bread, respectively. The specific human energy consumed were 5.35, 5.42 and 10.72 kJ kg^{-1} for magr baladi bread, mawi baladi bread and French bread, respectively. The specific thermal energy consumed were 2990.50, 2786.10 and 4752.89 kJ kg^{-1} for magr baladi bread, mawi baladi bread and French bread, respectively, which represent 98.43, 98.38 and 98.54% of the total energy consumed. The Total costs of different types of bread baking were 2.32, 1.76 and 4.80 LE kg^{-1} for Magr baladi, Mawi baladi and French bread, respectively.

Keywords: Thermal Energy, Electrical Energy, Human Energy, bread, baking

1. INTRODUCTION

Energy is one of the most important parameters in the manufacturing industries. In most cases, energy cost outweighs the costs of other resources such as raw material, labors, depreciation and maintenance **(Fadare, 2003)**. Scientific production and analysis of energy consumption will be of great importance for the planning of energy strategies and policies.

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Nowadays, energy usage in agriculture has been intensified in response to continued growth of human population, tendency for an overall improved standard of living and limited supply of arable land; thus, the farmers use their inputs in excess and inefficiently, particularly when the inputs have low price or are available in plenty. The enhancement of energy efficiency not only helps in improving competitiveness through cost reduction, also results in minimized energy-related environmental pollution, thus positively contributing towards sustainable development **(Kizilaslan, 2009 and Ghorbani *et al.*, 2010)**.

Bread production occurs on a number of different scales, from the artisan bakeries serving the local community, to the large commercial bakeries serving entire nations, as well as in-store supermarket bakeries, small chain outlets and anything in between. Baking ovens come in a variety of different configurations, from small domestic units to large tunnel ovens. Industrial ovens are typically gas powered and are usually classified as direct (forced convection), indirect, microwave, radiation, or infrared systems **(Keskin *et al.*, 2004; Mirade *et al.*, 2004; Sakin *et al.*, 2009; Khatir *et al.*, 2012; Khater and Bahnasawy, 2014**). Other energy sources include oil, electricity and woodchip burners. Previous studies in the baking industry estimate that the specific energy consumption of a bread oven is typically anywhere between 0.5 and 7.3 MJ/kg production **(Le Bail *et al.*, 2010)**.

Baking is an energy-intensive process due to water evaporation occurring in the product (latent heat of water vaporization is 2.257 MJ kg^{-1} at 100 °C). The energy demand for a conventional baking process is around 3.7 MJ kg^{-1}, though it can be higher (up to 7 MJ kg^{-1}) depending on specific products and operating conditions. In this sense, baking is similar to (conventional) drying, both demanding a high amount of energy in comparison with chilling, freezing, and canning, which need less than 1 MJ kg^{-1} **(Le Bail *et al.*, 2010)**.

There are approximately 18,000 baladi bakeries in Egypt. 90% are privately owned and 10% are publicly owned. The public bakeries have an average throughput of 7 tons of flour per day while the private bakeries average 1 ton per day. Bakeries pay 160 LE t^{-1} for subsidised flour. Note

that if the price of wheat was US$200 t^{-1}, the unsubsidised price of flour would be in excess of 1,100 LE t^{-1}. The technology used in the bakeries appears to be fairly uniform, with similar oven sizes and designs. The Egyptian Government provides a range of subsidised goods and services to the Egyptian people, including subsidised (baladi) bread. The Egyptian Ministry of Finance estimates that approximately 12-13 billion LE is spent per year on subsidising Baladi bread and flour, which equates to roughly 1.5% of Gross Domestic Product (GDP) **(World Bank, 2010)**.

There is no known report in the literature on the energy requirements of bread baking as practiced in Egypt. Such information is vital so as to enable the management of this industry to develop strategies for better control of their production operations and modify areas of waste. It will also enable the management to properly appraise their energy consumption for effective planning of production network. The study will provide an opportunity for having a reliable database concerning consumption of some types of energy by different users in bread baking. It will also provide a firm basis of identifying options for saving energy in bread baking operations; therefore, the main aim of the present work is to study and evaluate energy consumption of baking of different types of breads.

2. MATERIALS AND METHODS

The main experiment was carried out at the three local bakeries ovens, Moshtohor, Toukh, Kalubia Governorate, Egypt, during the period of 2015 season to evaluate of energy consumption in the baking of different types of breads.

2.1. Bread baking ovens description:

The stages of the bread baking are: material receiving and ingredients weighing, mixing, fermentation, dividing, molding, proofing, baking and cooling. Magr baladi, Mawi baladi and French bread bakeries were included in this study.

Magr baladi baking oven consists of kneading machine, dividing machine, molding machine and baking oven. Kneading machine consists of mixing ban, kneading machine and motor. It is driven by 4 hp motor and having a gear box to control the speed of mixing depending on the

load. The mixing ban capacity is 150 kg of flour. The dividing machine dimensions are 1.7 m long, 1.0 m wide and 1.55 m high. Its capacity is 200 kg. It is driven by 2 hp motor and having a gear box to control the speed.

The molding machine consists of two parts, each part consists of belt and motor. The dimensions of belt in first part are 1.43 m long, 0.46 m wide and 0.95 m high. The dimensions of belt in second part are 1.45 m long, 0.46 m wide and 0.79 m high. Each part is driven by 2 hp motor and having a gear box to control the speed.

The oven baking consists of belt and motor with 60 loaves for capacity. The belt is driven by 4 hp motor and having a gear box to control the speed of baking depending on the load. The length of belt is 4 m with a forward speed of 5.3 cm s^{-1}. Figure (1) shows the stages of bread baking in magr baladi bread.

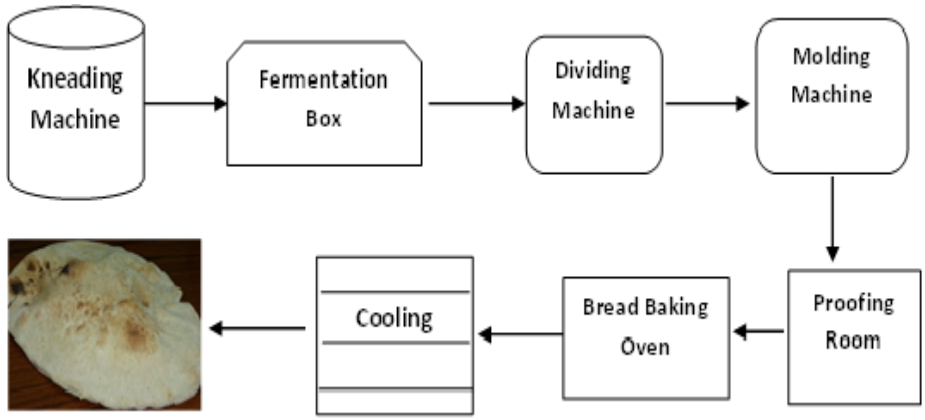

Figure (1): Stages of baking in Magr baladi bread bakery.

Mawi baladi bread bakery which consists of kneading machine and oven baking. Kneading machine similar to that of the Magr baladi oven. The oven baking consists of belt and motor with 60 loaves capacity. The belt is driven by 4hp motor and having a gear box to control the speed of baking depending on the load. The length of belt is 3 m and the speed is 2.2 cm s^{-1}. Figure (2) shows the stages of baking in mawi baladi bread.

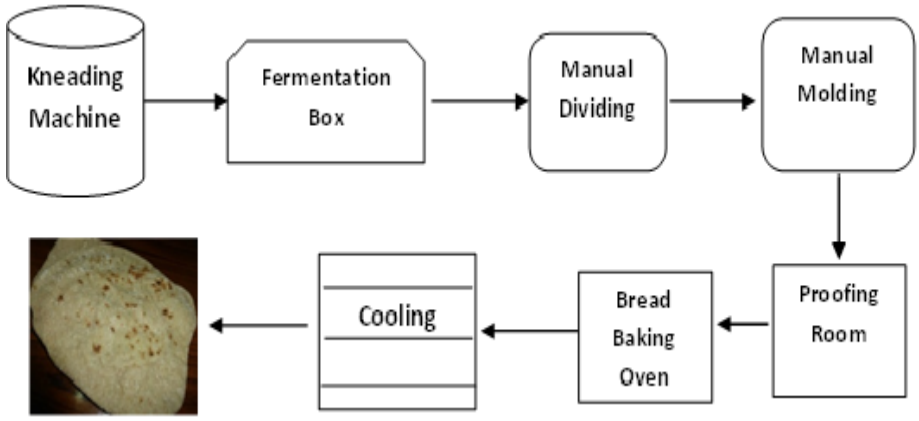

Figure (2): Stages of baking in Mawi baladi bread bakery.

French bread bakery consists of kneading machine and oven baking. Kneading machine consists of mixing ban, kneading machine and motor. It is driven by 2 hp motor and having a gear box to control the speed of mixing depending on the load. The mixing ban capacity is 100 kg of flour. The oven baking consists of 4 shelves. Dimensions of the oven are 2 m long, 1 m wide and 2 m high. The distance between shelves is 50cm. Load of each shelf is 42 loaves (45 g loaf^{-1}). Figure (3) shows the stages of French bread bakery.

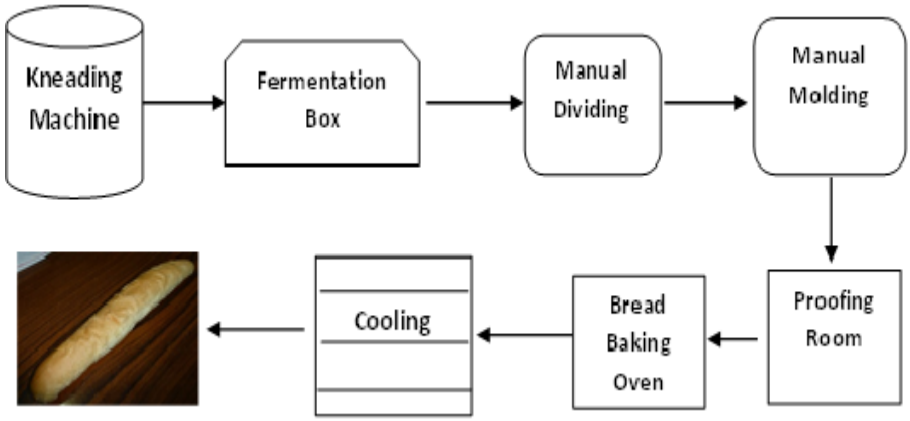

Figure (3): Stages of French bread bakery.

2.2. Measuring devices:

The power requirement (kW) was determined by recording the voltage and current strength by using the clamp meter (Model DT266 - Measuring

range 200/1000A and 750/1000V with an accuracy of ± 0.01, China) to measure the line current strength (I) and the potential difference value (V).

2.3. The specific energy consumption:

The total energy consumption (electrical, human and thermal) for each component was calculated for the production of finished bread baking for three oven types. The procedures were used:

Electrical energy consumption was estimated from the measured electric current and voltage values and estimated according to **Kurt (l979)** as follows:

$$E_p = \frac{\sqrt{3} \times I \times V \times \eta \times \cos\varphi}{1000 \times \mathrm{Pro}} \quad (1)$$

Where:

E_p is the electrical energy, kJ kg^{-1}

I is the electric current, Amperes.

η is the Mechanical efficiency assumed to be 0.95 **(Metwally, 2010).**

Vis the electrical voltage, V

cosφ is the Power factor being equal to 0.84

Pro is the productivity, kg s^{-1}

According to **Odigboh (1997)**, at the maximum continuous energy consumption rate of 0.30 kW and conversion efficiency of 25%, the physical power output of a normal human labor in tropical climates is approximately 0.075 kW sustained for an 8–10 h workday. This was calculated mathematically as:

$$E_m = \frac{0.075N}{\mathrm{Pr}o} \quad (2)$$

Where:

E_m is the Human energy, kJ kg^{-1}

N is the number of persons involved in an operation.

Machine productivity was determined by dividing product mass by time, Mg h^{-1}.

Thermal energy consumption was estimated from equation:

$$E_T = \frac{m \times hv}{\mathrm{Pr}\, o} \quad (3)$$

Where:

E_t is the thermal energy, kJ kg^{-1}

m is the mass flow rate, kg s^{-1}

hv is the heating value of disel, 42000 kJ kg^{-1} **(Shahin *et al.*, 2008)**

2.4. Total Costs:

Hourly cost is calculated according to the equation that is given by **Awady (1978)** as follows:

$$C = \frac{p}{h}\left(\frac{1}{a} + \frac{i}{2} + t + r\right) + (\mathrm{w} \times \mathrm{e}) + \frac{\mathrm{m}}{\mathrm{k}} \quad (4)$$

Where:

C is the hourly cost, LE h^{-1}

p is the price of the equipment, LE

h is the year by working hours, h

a is the life expected of the machine, year

i is the Interest rate, %

t is the taxes and over heads ratio, %

r is the repair and maintenance ratio, %

w is the power of motor in, kW

e is the electricity cost, LE kW^{-1} h^{-1}

m is the operator monthly salary, LE.

k is the monthly average working hours.

Cost inputs are listed in table (1).

Table (1): Cost inputs.

Items	Equipment				
	Kneading machine	Dividing machine	Molding machine	Oven baking	French oven baking
Price of equipment, LE.	16000	11000	7000	24000	28000
Motor, kW	3.0	1.5	1.5	3.0	2.0
Life expected, year	10				
Taxes, %	3				
Repair, %	10				
Interest, %	10				
Labors, LE h^{-1}	10				

3. RESULTS AND DISCUSSIONS

3.1. Energy Consumed in bread baking oven:

- Magr baladi bread baking:

Table (2) shows the energy consumed in the Magr baladi bread baking and figures (4 and 5) show the energy flow diagram and percentages of energy consumption in the bread baking. It could be seen that, the total energy consumed is divided into three types, namely, electrical, human and thermal energies. The results indicated that the total energy consumed was 3038.07 kJ kg^{-1}. The electrical energy required for bread baking was 42.21 kJ kg^{-1} (1.39%), where, the human energy consumed was 5.35 kJ kg^{-1} (0.18%). The results also indicate the thermal energy for bread baking was 2990.50 kJ kg^{-1} which is considered the highest rate in the consumption of total energy in the bread baking and represented 98.43% of the total energy consumed in bread baking. These results agreed with those obtained by **Le Bail *et al.* (2010)** whose found that the energy consumption of a bread is typically anywhere between 0.5 and 7.3 MJ kg^{-1} production (500 and 7300 kJ kg^{-1}). Mixing process consumed an

electrical energy of 15.8 kJ kg^{-1} which represented 37.43% of total electrical energy in whole process of baking (42.21 kJ kg^{-1}).

The results also indicate that the specific energy consumed of raw material receiving was 0.069 kJ kg^{-1} (0.002%). The specific energy consumed of handling was 3.055 kJ kg^{-1} (0.10%). The specific energy consumed of maxing was 16.057 kJ kg^{-1} (0.529%). The specific energy consumed of dividing was 13.490 kJ kg^{-1} (0.444%). The specific energy consumed of molding was 6.029 kJ kg^{-1} (0.198%). The specific energy consumed of baking was 2998.45 kJ kg^{-1} which is considered the highest rate in the consumption of total energy in the bread baking oven and represented 98.695% of the total energy consumed in bread baking oven. The specific energy consumed of packing was 0.958 kJ kg^{-1} (0.032%).

Table (2): The energy consumed in the Magr baladi bread baking.

Process sequences	Process	Total energy consumed, kJ kg^{-1}			Total energy consumption, kJ kg^{-1}	% of total energy consumption
		Electrical energy, kJ kg^{-1}	Human energy, kJ kg^{-1}	Thermal energy, kJ kg^{-1}		
1	**Raw material receiving**	….	0.069	….	0.069	0.002
2	**Handling 1 (to kneading machine)**	….	0.069	….	0.069	0.002
3	**Mixing**	15.812	0.245	….	16.057	0.529
4	**Handling 2(to container or troughs)**	….	0.076	….	0.076	0.003
5	**Fermentation**	….	….	….	….	….
6	**Handling 3(to fine bran on wood slabs)**	….	0.735	….	0.735	0.024
7	**Dividing**	13.490	….	….	13.490	0.444
8	**Molding**	6.029	….	….	6.029	0.198
9	**Handling 4(to Proofing)**	….	0.553	….	0.553	0.018
10	**Proofing**	….	….	….	….	….
11	**Handling 5(to the ovens)**	….	0.627	….	0.627	0.021
12	**Baking**	6.883	1.026	2990.50	2998.45	98.695
13	**Handling 6 (from the belt)**	….	0.801	….	0.801	0.026
14	**Handling 7 (to cooling)**	….	0.194	….	0.194	0.006
15	**Cooling**	….	….	….	….	….
16	**Packing**	….	0.958	….	0.958	0.032
17	**Total**	42.213	5.353	2990.50	3038.066	100
18	**% of total energy consumption**	1.39	0.18	98.43	100	100

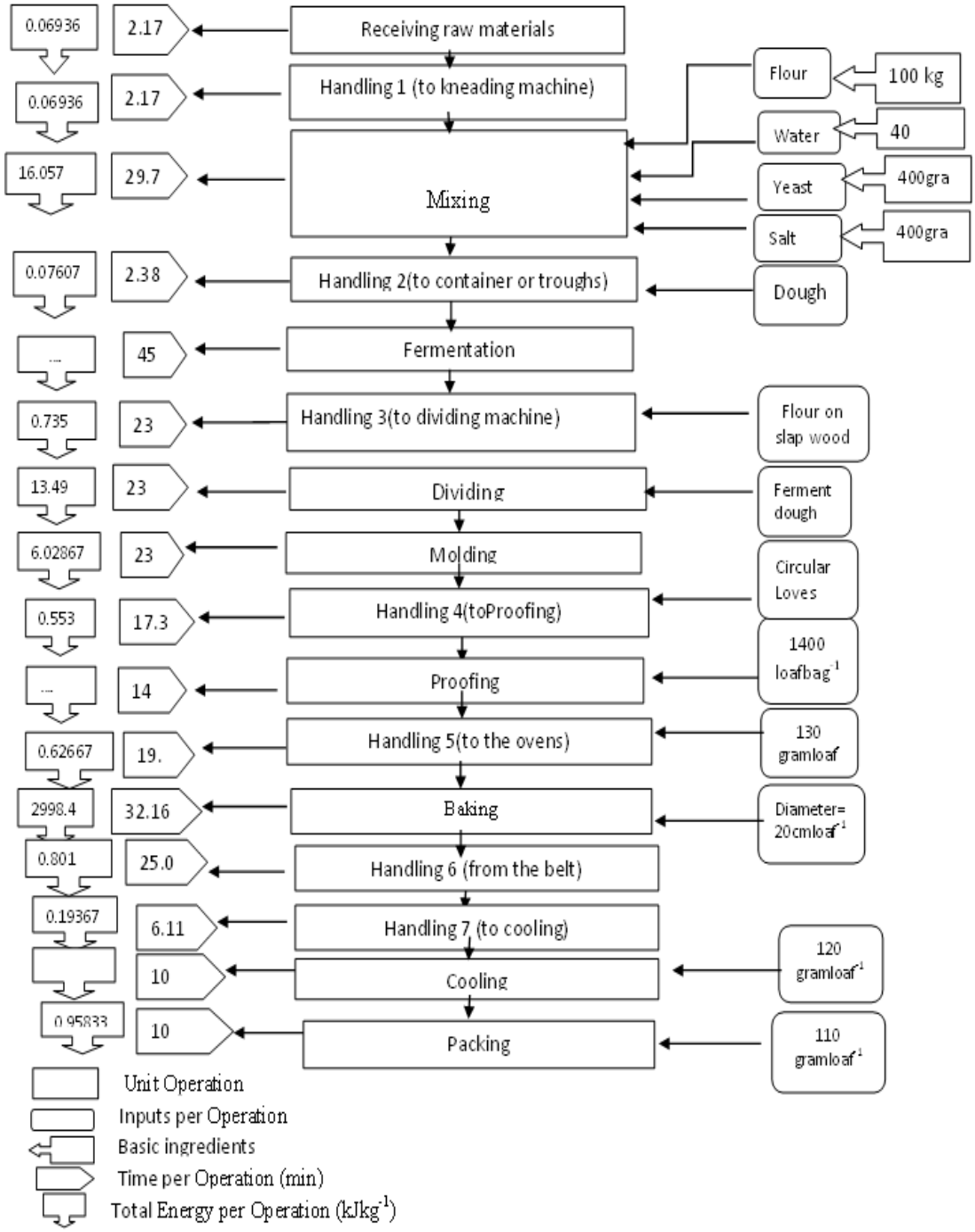

Figure (4): Energy flow diagram of Magr baladi bread baking.

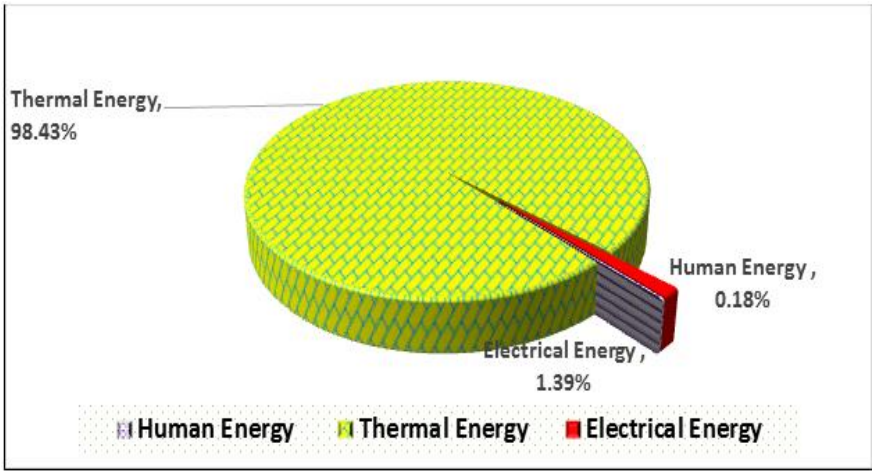

Figure (5): The percentages of energy consumption Magr baladi bread baking.

- Mawi baladi bread baking:

Table (3) shows the energy consumed in the Mawi baladi bread baking and figures (6 and 7) show the energy flow diagram and percentages of energy consumption in the bread baking. It could be seen that, the total energy consumed is divided into three types, namely, electrical, human and thermal energies. The results indicated that the total energy consumed was 2831.851 kJ kg^{-1}. The electrical energy required for bread baking was 40.33 kJ kg^{-1} (1.42%), where, the human energy consumed was 5.42 kJ kg^{-1} (0.19%). The results also indicate the thermal energy for bread baking was 2786.10 kJ kg^{-1} which is considered the highest rate in the consumption of total energy in the bread baking oven and represented 98.38% of the total energy consumed in bread baking oven. These results agreed with those obtained by **Le Bail *et al.* (2010)**. Mixing process consumed an electrical energy of 18.70 kJ kg^{-1} which represented 46.37% of total electrical energy in whole process of baking (40.33 kJ kg^{-1}).

The results also indicate that the specific energy consumed of raw material receiving was 0.069 kJ kg^{-1} (0.002%). The specific energy consumed of handling was 2.051 kJ kg^{-1} (0.063%). The specific energy consumed of maxing was 18.917 kJ kg^{-1} (0.668%). The specific energy consumed of dividing was 0.905 kJ kg^{-1} (0.0.032%). The specific energy consumed of molding was 0.487 kJ kg^{-1} (0.017%). The specific energy consumed of baking was 2808.611 kJ kg^{-1} which is considered the highest

rate in the consumption of total energy in the bread baking oven and represented 99.178% of the total energy consumed in bread baking oven. The specific energy consumed of packing was 0.837 kJ kg^{-1} (0.030%).

Table (3): The energy consumed in the Mawi baladi bread baking.

Process sequences	Process	Total energy consumed, kJ kg^{-1}			Total energy consumption, kJ kg^{-1}	% of total energy consumption
		Electrical energy, kJ kg^{-1}	Human energy, kJ kg^{-1}	Thermal energy, kJ kg^{-1}		
1	**Raw material receiving**	….	0.069	….	0.069	0.002
2	**Handling 1 (to kneading machine)**	….	0.061	….	0.061	0.002
3	**Mixing**	18.703	0.213	….	18.917	0.668
4	**Handling 2(to container or troughs)**	….	0.067	….	0.067	0.002
5	**Fermentation**	….	….	….	….	….
6	**Handling 3(to fine bran on wood slabs)**	….	0.010	….	0.010	0.001
7	**Dividing**	….	0.905	….	0.905	0.032
8	**Molding**	….	0.487	….	0.487	0.017
9	**Handling 4(to Proofing)**	….	0.487	….	0.487	0.017
10	**Proofing**	….	….	….	….	….
11	**Handling 5(to the ovens)**	….	0.553	….	0.553	0.020
12	**Baking**	21.63	0.857	2786.10	2808.61	99.178
13	**Handling 6 (from the belt)**	….	0.70	….	0.70	0.025
14	**Handling 7 (to cooling)**	….	0.173	….	0.173	0.006
15	**Cooling**	….	….	….	….	….
16	**Packing**	….	0.837	….	0.837	0.030
17	**Total**	40.333	5.418	2786.10	2831.851	100
18	**% of total energy consumption**	1.42	0.19	98.38	100	100

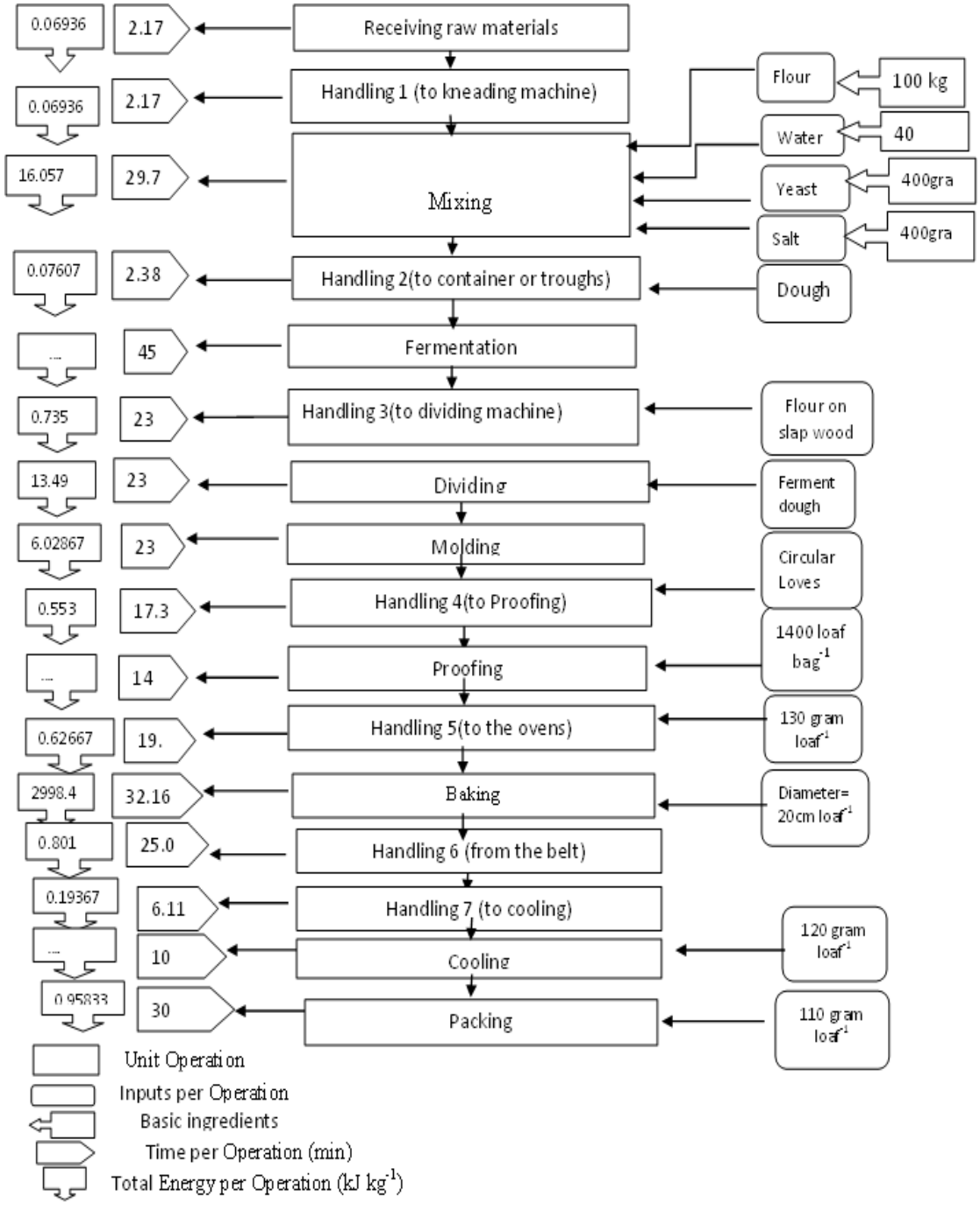

Figure (6): Energy flow diagram of Mawi baladi bread baking.

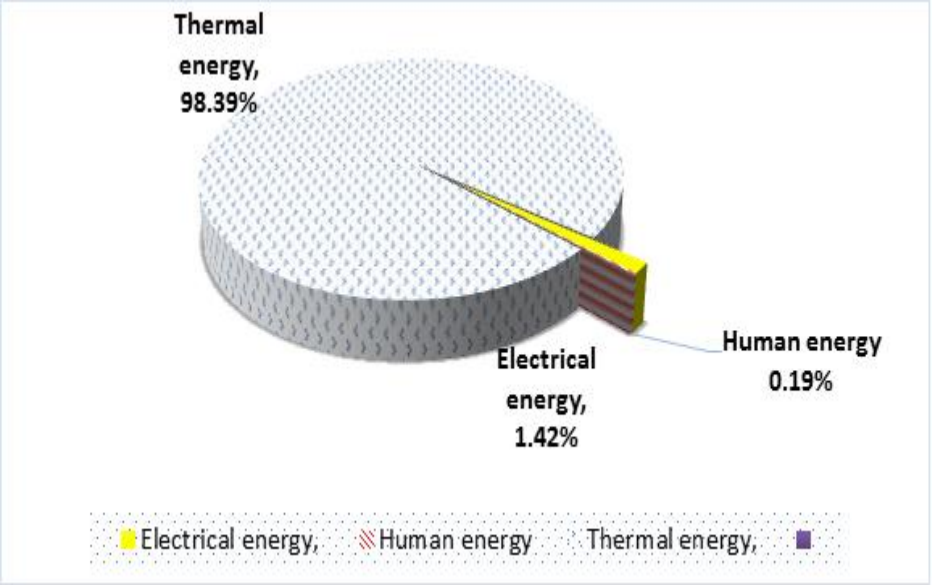

Figure (7): The percentages of energy consumption Mawi baladi bread baking.

- French bread baking:

Table (4) shows the energy consumed in the French bread baking and figures (8 and 9) show the energy flow diagram and percentages of energy consumption in the bread baking. It could be seen that, the total energy consumed is divided into three types, namely, electrical, human and thermal energies. The results indicated that the total energy consumed was 4823.529 kJ kg^{-1}. The electrical energy required for bread baking was 59.917 kJ kg^{-1} (1.24%), where, the human energy consumed was 10.751 kJ kg^{-1} (0.22%). The results also indicate the thermal energy for bread baking was 4752.892 kJ kg^{-1} which is considered the highest rate in the consumption of total energy in the bread baking oven and represented 98.54% of the total energy consumed in bread baking oven. Mixing process consumed an electrical energy of 34.42 kJ kg^{-1} which represented 57.44% of total electrical energy in whole process of baking (59.92 kJ kg^{-1}).

The results also indicate that the specific energy consumed of raw material receiving was 0.069 kJ kg^{-1} (0.001%). The specific energy consumed of handling was 2.425 kJ kg^{-1} (0.051%). The specific energy

consumed of maxing was 34.757 kJ kg^{-1} (0.721%). The specific energy consumed of dividing was 3.889 kJ kg^{-1} (0.081%). The specific energy consumed of molding was 2.608 kJ kg^{-1} (0.054%). The specific energy consumed of baking was 4778.461 kJ kg^{-1} which is considered the highest rate in the consumption of total energy in the bread baking oven and represented 99.065% of the total energy consumed in bread baking oven. The specific energy consumed of misting water was 1.32 kJ kg^{-1} (0.029%).

Table (4): The energy consumed in the French bread baking.

Process sequences	Process	Total energy consumed, kJ kg^{-1}			Total energy consumption, kJ kg^{-1}	% of total energy consumption
		Electrical energy, kJ kg^{-1}	Human energy, kJ kg^{-1}	Thermal energy, kJ kg^{-1}		
1	**Raw material receiving**	….	0.0688	….	0.0688	0.001
2	**Handling 1 (to kneading machine)**	….	0.062	….	0.0623	0.001
3	**Mixing**	34.417	0.340	….	34.757	0.721
4	**Handling 2(to table for fermentation)**	….	0.143	….	0.143	0.003
5	**Fermentation**	….	….	….	….	
6	**Dividing**	….	3.889		3.889	0.081
7	**Molding**	….	2.608	….	2.608	0.054
8	**Handling 3(to fermentation room)**	….	0.420	….	0.420	0.009
9	**Proofing**	….	….	….	….	
10	**Handling 4(to the ovens)**	….	0.420	….	0.420	0.009
11	**Baking**	25.50	0.069	4752.892	4778.461	99.065
12	**Misting water**	….	1.32	….	1.32	0.027
13	**Handling 5 (to Consumer)**	….	1.38	….	1.38	0.029
14	**Total**	59.917	10.721	4752.892	4823.529	100
15	**% of total energy consumption**	1.24	0.22	98.54	100	

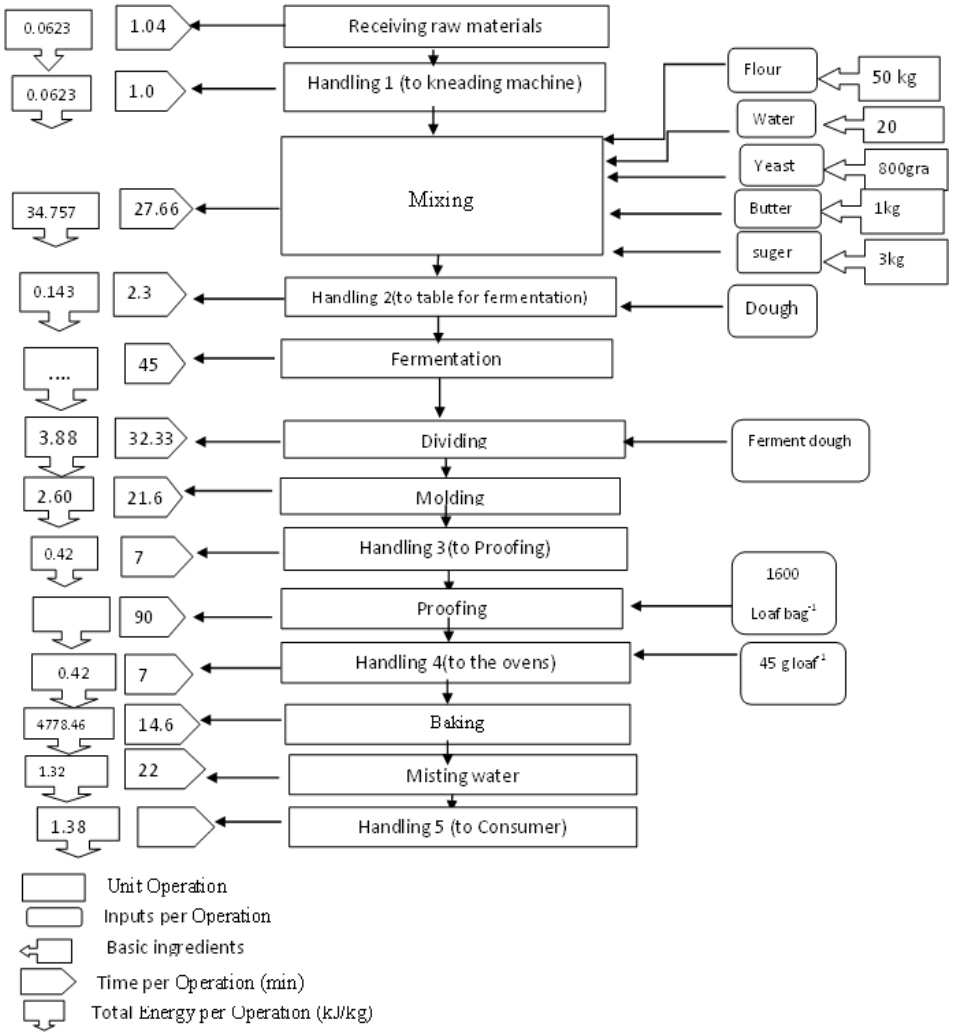

Figure (8): Energy flow diagram of the French bread baking.

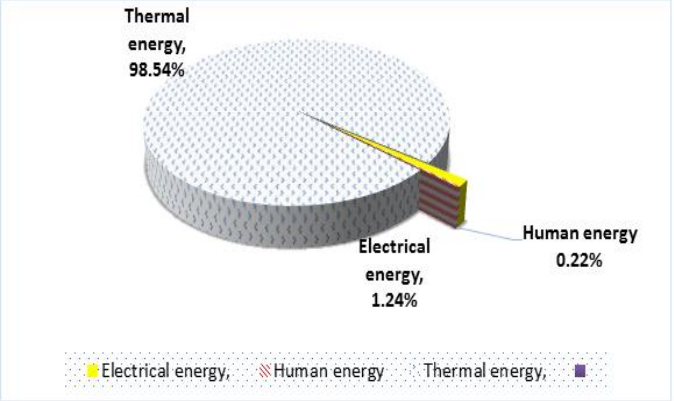

Figure (9): The percentages of energy consumption in the French bread baking.

3.2. Comparison between the specific energy consumption of different bread baking ovens types:

Table (5) and figure (10) show the specific energy consumed in different bread baking bakeries. It could be seen that the specific energy consumed in bread baking bakeries were 3038.11, 2831.85 and 4823.53 kJ kg^{-1} for Magr, Mawi and French bread bakeries, respectively. The highest value of energy consumed (4823.53 kJ kg^{-1}) was found for French bread bakery, while, the lowest value of energy consumed (2831.85 kJ kg^{-1}) was found for Mawi baladi bread bakery which is lower by about 2000 kJ kg^{-1} which is due to the Mawi bread baking took less time to produced.

Table (5): Specific energy consumed in different types of bakeries.

Type of bakery	Specific energy consumed			Total energy consumption, kJ kg^{-1}
	Electrical energy, kJ kg^{-1}	Human energy, kJ kg^{-1}	Thermal energy, kJ kg^{-1}	
Magr bread bakery	42.21	5.35	2990.50	3038.11
Mawi bread bakery	40.33	5.42	2786.10	2831.85
French bread bakery	59.92	10.72	4752.89	4823.53

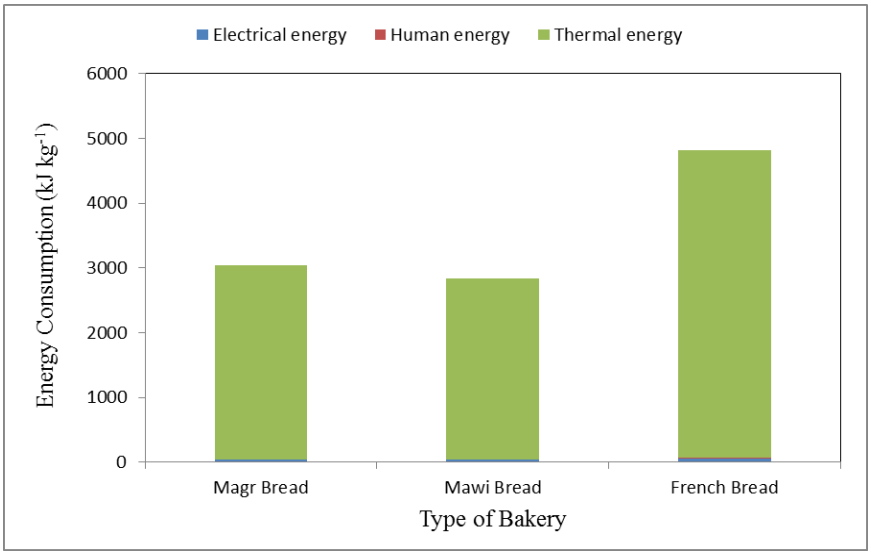

Figure (10): Specific energy consumed in different types of bakeries.

3.3. The total costs of different types of breads:

Figure (11) shows the estimated costs of different types of bread baking bakeries. It could be seen that the total cost was 2.32 LE kg^{-1} for Magr baladi bread oven as compared with 1.76 LE kg^{-1} for Mawi baladi bread, while, the total costs for the French bread was much higher than that of both Magr baladi and Mawi baladi ovens, where it recorded 4.80 LE kg^{-1}. It could be concluded that to produce one kg of French bread costed 2.07 and 2.73 times of that of Magr baladi bread and Mawi baladi bread, respectively.

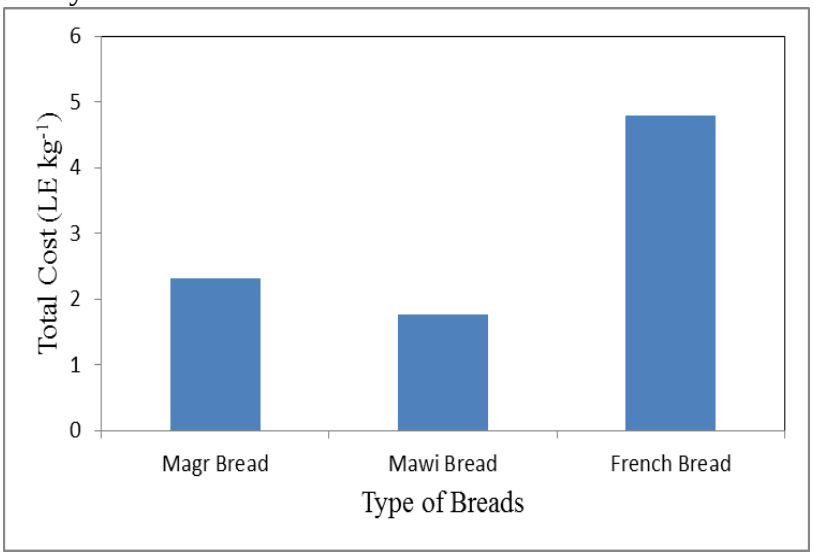

Figure (11): The total costs of different types of bread baking.

4. CONCLUSION

The experiment was carried out to evaluate energy consumption in different types of bread baking. Three types of energy were used in bread baking oven, namely, electrical, human and thermal energies. The thermal energy represented the most energy consumed, where, it ranged from 98.38- 98.54% of the total energy consumed in bread baking. Human energy ranged from 0.18 – 0.22% of the total energy consumed in bread baking. Electrical energy ranged from 1.24 - 1.42% of the total energy consumed in bread baking. The Total costs of different types of bread baking were 2.32, 1.76 and 4.80 LE kg^{-1} for Magr baladi, Mawi baladi and French breads, respectively.

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الملخص العربى

استهلاك الطاقة فى تصنيع الخبز

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تهدف هذه الدراسة الى تقدير الطاقة المستهلكة فى تصنيع الخبز وذلك من خلال تقدير الطاقة المستهلكة فى المراحل المختلفة وتحديد نوعيتها فى ثلاث أنواع مختلفة من الافران. وقد اثبتت النتائج ان استهلاك الطاقة فى تصنيع ١ كجم من الخبز فى ثلاث أنواع من الأفران ٣٠٣٨.١١ و٢٨٣١.٨٥ و 4823.53 كجول كجم$^{-1}$ فقط، على التوالى. حيث تمثل الطاقة المستهلكة من احتراق الوقود فى تصنيع الخبز من ٩٨.٣٨ – ٩٨.٥٤% وتمثل الطاقة البشرية المستخدمة فى تصنيع الخبز من ٠.١٨ – ٠.٢٢%، وتمثل الطاقة الكهربية المستخدمة فى تصنيع الخبز من ١.٢٤ – ١.٤٢%. وكانت تكليفة انتاج ١ كجم خبز هى ٢.٣٢ و١.٧٦ و٤.٨٠ جنيه لكل من الخبز المجر والماوى والفرنساوى على الترتيب.

***قسم الهندسة الزراعية- كلية الزراعة- جامعة بنها.**