Ergonomic Evaluation and Energy Requirements of Bread-baking Operations in South Western Nigeria

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ABSTRACT

A study was conducted in three southwestern states of Nigeria to evaluate the energy requirements and man-machine relationships in bread-baking operations. The study, which lasted over one year, involved the use of three fuel sources namely, firewood, electricity and cooking gas during bread baking operations. Questionnaire and physical measurements were employed for data collection from fifty bakeries randomly selected within the study area. The data points include the environmental and body temperatures, anthropometrical data, bio data, injury data, metabolic and production measurements.The results of the study revealed that bread-baking with wood as energy source required the highest energy (6.15 kJ/min) compared with 3.37 kJ/min and 1.52 kJ/min obtained with gas and electricity as sources of energy respectively. The cost of energy per kg of baked bread was ₦7.58 ($ 0.059) with cooking gas as the energy source followed by ₦6.05 ($ 0.047) for electricity and ₦5.05 ($ 0.04) for wood in that order. The average baking rate using firewood, gas and electricity as energy sources were 11.92 kg/h, 17.97 kg/h and 20.58 kg/h respectively. Analysis of metabolic data showed moderate increase in the subjects' body temperatures, blood pressures and heart rates after bread baking operations. Epidemiological study showed that all age groups sustained bakery injuries while using various implements. More than 80% of the victims were workers below 34 years of age. The study suggests that bread-baking operations could be categorized as a light grade work and that the use of electricity as energy source is the most appropriate in terms of bread baking rate and unit energy requirement.

Keywords: Bread baking, gas, firewood, electricity, ergonomics, energy requirement, Nigeria.

1. INTRODUCTION

Bread, a product of wheat, is a highly nutritious food eaten in one form or another by nearly every person on earth. Bread, which is an excellent source of vitamins, protein and carbohydrates, has been an essential element of human diet for centuries in all regions. The operations of bread baking tend to be labour intensive with little available equipment like mixer, kneading machine, milling machine and divider.

Mixing of flour, water, yeast and other ingredients to form dough is often done by hand in trough or on tabletop. This operation involves mixing flour with fat, salt, water and yeast. Where mechanical mixer is used, the mechanical work done by the blades of the

dough mixer starts to stretch the fiber of the gluten, the protein of the flour. The overall success of bread baking starts from the success of mixing. Development of dough may be by hand kneading but rollers are commonly used through which the dough is passed repeatedly. Kneading involves stretching and folding of dough until its consistency becomes smooth.

The mixed dough is placed in metal container or troughs to allow the mixed dough to ferment. Varying fermentation periods are used in different processes. At the end of this period, the dough would have risen to the top bowl. Dividing the dough into individual pieces can be by bun-divider. The kneaded dough is then molded into desired shape usually by hands or mechanically by a molder which rolls the pieces into balls and drops them into a series of slowly moving pockets, which travel in a temperature – controlled compartment called prover.

Proving, a process which allows the dough to rise is usually done in the open place near the bakery shop. The sausage-shaped pieces of fermenting dough are put into individual baking tins. The baking tins containing the dough are now conveyed to the oven. During the first stages in the oven, the dough continues to ferment and increases in volume. After the dough is placed in the oven, the temperature is increased. After about 30 to 45 minutes depending on the type of oven, the bread is ready for depanning which is the last stage of bread baking operation.

In Nigeria, local fabricators of agro-processing equipment have designed and manufactured various improvised versions of imported bread-baking machines without due ergonomic considerations. In spite of these few locally fabricated machines, most of the processes of bread baking in Nigeria largely involve Manual Materials Handling (MMH) which continues to represent a major loss source in the work place (Dempsey, 2003). The manual operations besides being uncomfortable are characterized by low output and unhygienic products. For instance, these losses were reported (Dempsey, 2003) to represent approximately 30% of incidences and direct cost in the UK and US (David, 1985; Dempsey & Hasheni, 1999; Nicholson, 1985).

Bread baking operations especially those involving the baking (in oven) stage are accomplished by the use of thermal energy and the heat for baking is derived from different fuel sources. Fuels are materials consumed by burning to generate energy suitable for human needs (Rajput, 2001). The major sources of energy used for bread baking in Nigeria are fuel wood, gas and electricity, which at the moment are not only scarce but costly. This is due to epileptic nature of electricity supply from the national grid on the one hand and shortage in supplies of petroleum products and the continuous disappearance of natural forest on the other hand. In most bakeries in Nigeria, manual bread baking operations which are carried out under hot environmental conditions involve the use of rudimentary tools, and therefore have a lot to do with muscles which are energy sapping. The health of the bakers may be endangered due to large amount of poisonous exhaust gases they inhale as a result of incomplete combustion.

All the bread-baking operations from flour mixing to depanning involve the interaction between man, machines and his working environment (Staudt, 1975). Any working position which involves an unnatural posture, a twisted trunk or/and extended arm position will create undue fatigue and reduce production output (Dempsey & Hashemi, 1999).

Factors, which act upon the working capacity and the daily production, are the individual characteristics such as sex, age, body-size, physical fitness, nutritional and health state (Aiyelari, Ndaeyo & Hyuma, 1998). Other important factors include the physical environmental factors such as hot or cold climate and high altitude (Nag & Pradhan, 1985). It has also been observed (Staudt, 1975) that psychological, cultural, economical, technological and organizational factors also act upon man's working capacity and production.

Similar works on energy requirements and ergonomic consideration of food and agricultural processing operations have been reported in literature. Baruah & Bhattacharya (1996) studied the utilization pattern of human and fuel energy in tea plantation in India. Aiyelari, Ndaeyo & Hyuma, (1998) evaluated the power requirements in gari (cassava) frying in Nigeria. Cleland, Earle & Baag (1981) proposed the application of Multiple Linear Regression to analysis of data from food factory energy surveys. Cundiff & Dodd (1981) developed mathematical models that could estimate energy requirements for forced air tobacco curing. Chang, Chang and Kim (1996) conducted a study to develop an energy model and a computer simulation model which could assess the requirements of electricity, fuel and labour for rice handling, drying, storage, and milling processes of rice processing complex in Korea. Jekayinfa and Bamgboye (2003, 2004, 2006, and 2007) conducted a study to determine the efficiency and pattern of energy usage in some selected cashew nut and palm-kernel oil processing mills in Nigeria. Jekayinfa (2006, 2007) reported work done on energy analyses of operations in selected mechanized farms and poultry processing operations in Nigeria. This study was conducted to:

(i) determine the baking rate, energy cost and unit energy requirement using different energy sources,
(ii) evaluate the anthropometrical characteristics of bakery workers in relation to different energy sources available and.
(iii) assess the magnitude of bakery-related injuries

It is hoped that the outcome of this study would assist in determining an appropriate source of energy in terms of cost, unit energy requirement and baking rate. The outcome of the study on environmental heat stress on bakers and bakery-related injuries would also be useful to equipment designers in the fabrication of ergonomically advantageous baking machines.

2. MATERIALS AND METHOD

The study was conducted in Lagos, Oyo and Osun States of Nigeria during the production years of 2002 and part of 2003. The choice of these South Western States of Nigeria stems from the fact that over 80% of food manufacturing industries in this location deal with bread-baking ventures (Federal Republic of Nigeria, 2001). The study involved 50 bakeries scattered around major towns and cities within the study area.

2.1 Materials/Equipment Used

The following materials/equipment were used in the course of the study:

(i) A stop watch for measuring unit operation time parameters
(ii) A measuring cylinder for quantifying the amount of liquid fuel consumed during bread-baking operations.

(iii) A stethoscope for measuring heart beats of bakery workers before and after each operation
(iv) A clinical thermometer for measuring body temperature of bakery workers
(v) A mercury-in-glass thermometer for environmental temperature measurement
(vi) A weighing instrument for measuring bakery workers and materials flow through the bakery operations
(vii) A solid measuring tape for measuring subjects' heights.

2.2 Methods

A total of 150 subjects were used for the research using three energy sources viz: fire wood, gas and electricity. Wood was bought directly from nearby markets in bunches of 1000kg – 1500kg for ₦6, 000 ($ 47); Gas was bought at ₦5, 000 ($ 39.20) per 50 kg cylinder load while electricity was obtained from the national grid at the rate of ₦ 50 ($ 0.39) per kWh. The subjects used for the experiments were between 15 and 45 years of age and ascertained by a physician to be in good conditions of health. These people have been involved in bread baking operations for more than 5 years and the rationale behind the study was explained to them. The subjects were grouped into categories representing different age, body weight, height (stature) and baking experience. Each identified category cuts across all the energy treatments. The baking operations in all the bakeries used took place both in the morning and evening periods. The humidity ranged between 58 and 73% during the study period in the bakeries environments.

Questionnaire was used for biodata collection while the metabolic and production data were obtained by physical measurement of each subject. These methods of data collection were used in similar reported work of Aiyelari, Ndaeyo & Hyuma (1998); Aiyelari, Cole & Alabadan (1997); Cole & Ogungbe (1987); and Lehman (1962). Equal number of subjects was used for each energy treatment (Vanloon, 1990; Aiyelari, Ndaeyo & Hyuma, 1998). Anthropometric data (age, body weight, height, and arm and leg length) were obtained both through questionnaire and direct measurement; environmental temperature in all bakeries was measured using mercury in glass thermometer; heart rate of each subject was measured before and after each operation using a stop watch and stethoscope, subjects' body temperature was measured using a clinical thermometer. The quantity of bread baked and the time involved in each processing operation for each energy source treatment were also determined. The quantity of energy used (firewood and gas) in each energy treatment case was determined before the baking process using portable weighing balance. For electricity consumption, the electricity-metering device installed in each bakery by the National Electric Power Authority (NEPA) was used for measuring the quantity of electricity consumed.

Quantity of fuel consumed in the use of mobile electricity generating plants for bread-baking operations was converted into equivalent energy (MJ) using appropriate coefficient [one litre of diesel = 47.8 MJ and one litre of gasoline = 42.3 MJ (Pimentel, 1992)]. The quantity of electricity consumed was obtained by converting NEPA metre readings (kWh) into common energy unit (MJ) by using appropriate coefficient [One kWh of electricity = 3.6 MJ (Pimentel, 1992)].

Survey workers also collected injury data from the selected bakeries. These workers visited every bakery once every two weeks and obtained epidemiological information on all injury –

related events for a period of 1 year. For every case reported, all information on equipment – related injury was obtained. Injuries from most processing machines are the unintentional consequences of action during operation of the machines (Mohan & Patel, 1992; Horsburgh, Feyer & Langley, 2001 and Mohan et al., 2004). According to The Abbreviated Injury Scale (AIS, 1990), injuries have been classified into AIS scores as summarized in Table 1.The data collected from individual bakeries were coded, tabulated and analysed using descriptive statistics.

3. RESULTS AND DISCUSSION

3.1 Anthropometrical Measurements

The results on anthropometrical measurements of the subjects in bakeries utilizing the three different energy sources are presented in Table 2. The data revealed that the mean age of the subjects in bakeries using wood, gas and electricity as energy sources were, respectively 28.9 years, 22.3 years and 22.7 years. The weight, height, arm length, and leg length of bakers in the three bakery categories were 57.60kg, 166cm, 72.82cm, 104.1cm; 57.50kg, 170.73cm, 73.50cm, 109.6cm and 57.85kg, 169.75cm, 73.65cm, 108.5cm respectively. The corresponding average years of baking experience of subjects in these bakeries were 5.90 years, 5.97 years and 5.87 years respectively. The results of the correlation analyses of the subjects' leg length, arm length and height (stature) in relation to the ERR for the three bakery categories showed no significant effect but negative relationship between leg length (cm) and ERR (kg/min) (r = - 0.15). Also the effect of arm length (r = - 0.17) and height (r = 0-11) on ERR was not significant in all the three bakeries. Based on the reports of Christenson (1964), Apud et al (1989) and Ayelari, Cole & Alabadan (1997), the maximum oxygen consumption (anaerobic power) of the bakers (from heart rate, beats/min) did not exceed the recommended value of between 75 and 100 beat/min for light work grade. Also, the heart rate values were low signifying that there was low oxygen consumption after the baking operation, an indication that there was no muscle fatigue which could have caused differences in ERR of the subjects.

Table 1.Injury severity and scale

Injury severity	AIS scale
Minor	1
Moderate	2
Serious not life threatening	3
Severe life threatening, survival probable	4
Critical survival uncertain	5

Source: AIS (1990)

Table 2.Anthropometrical measurement of the subjects used

Types of bakery		Age (Years)	Body weight (kg)	Height (cm)	Arm length (cm)	Leg length (cm)	Experience in bread baking (yr)
Wood as energy source	Mean	28.9	57.6	166	77.82	104.1	5.9
	S D	6.37	8.7	16.42	3.72	19.33	2.92
	Range	20-45	44.5-70.5	145-198	68.42-79.15	80-135	5-11
Gas as energy source	Mean	22.3	57.5	170.73	73.5	109.6	5.97
	S D	4.91	8.19	15	4.32	19.85	2.08
	Range	14-31	46-71	148-192	68.6-79.35	83-136	5-11
Electricity as energy source	Mean	22.7	57.85	169.75	73.65	108.5	5.87
	S D	4.85	8.65	16.75	4.12	19.65	2.15
	Range	16-32	46-72	149-195	69.75-78.65	85-138	5-11

SD Standard Deviation

3.2 Effects of Energy Sources on Energy Cost, Energy Expenditure Rate and Bread Baking Rate

Table 3 shows the energy cost from different sources and their influences on energy requirement rate and bread baking rate. The mean energy cost per kg of bread was ₦5.05, ₦ 7.58 and ₦ 6.05 for wood, gas and electricity, respectively. The use of gas resulted in the highest energy cost per kg of bread, followed by electricity and the lowest value was recorded for wood. The use of wood resulted in more energy requirement rate (6.15kJ/min), followed by gas (3.37 kg/min) and electricity (0.72 kJ/min) in that order. The highest baking rate of 20.58kg/h was obtained with the use of electricity, followed by 17.97 kg/h for gas and 11.92 kg/h for wood.

From the foregoing, it can be concluded that bread baking in terms of energy cost, (EC) energy requirement rate (ERR) and baking rate (BR) is best done with the use of electricity followed by gas in terms of ERR and BR. The situation on ground in most Nigerian bread baking factories is not in line with the findings of this study because of high initial capital of installing either gas - fired or electricity dependent bakeries. Most of the bakeries using wood are small scale in size and production capacity (Table 3).

In those bakeries where gas and electricity are used as energy sources, bread-baking rates are relatively high, ranging from 16 to 24.57kg/h as compared with an average bread-baking rate of 11.92kg/h recorded for bakeries using wood.

Gas, which showed the highest cost of energy per kg of bread, could be ascribed to its high efficiency, which makes its energy demand to be high. Electricity, besides being less costly than gas, is also environment-friendly in that it produces no smoke or exhaust fumes.

3.3 Effect of Energy Sources on Environmental Temperature and Change in Body Temperature, Blood Pressure and Heart Rate of Subjects during Bread-Baking Operations.

The data on environmental temperature and changes in body temperature, blood pressure and heart rate of subjects as influenced by the use of different energy sources are shown in Table 4. The results indicated that the mean maximum environmental temperature of 28.50^0C, 27.00^0C and 26.50^0C were respectively obtained when wood, gas and electricity were used as sources of energy. The mean maximum change in body temperature, percentage change in blood pressure and change in heart rate of subjects with bakeries utilizing wood were respectively 1.5^0C, 14.9% and 7.75. The corresponding values obtained for bakeries using gas and electricity were respectively 1.01^0C, 1.4%, 5.65 and 0.72^0C, 5.80%, 6.50.

The observed high increase in body temperature in bakeries using wood could be linked with their heating efficacy. This resulted in the longest recorded time of producing a unit quantity of bread. The long baking time under these bakeries compared to others resulted in the highest increases in body temperature of the subjects (bakers).

Similar higher increase in blood pressure and heart rates of subjects were observed in the subjects working in bakeries using wood as compared with other types of bakeries. However, the high increase in body temperature of the subjects did not adversely affect their

productivity since it did not exceed the limit reported by Wlyndham (1970), Bodley (1973), Byrium et al (1978) and Aiyelari, Ndeayo & Hyuma (1998).

Table 3.Energy cost (₦/kg, ₦/litre), energy requirement rate (kJ/min) and bread baking rates (kg/hr) for the three bakery categories

Source of Energy				
		Wood	Gas	Electricity
Energy cost *₦/kg of wood, ₦/kg of gas, ₦/kw-h of electricity	Mean	5.05	7.58	6.05
	Standard deviation	1.00	1.30	0.50
	Range	4.56 – 7.67	6.00 – 9.33	5.00 – 6.95
Energy requirement rate, kJ/min	Mean	6.15	3.37	1.52
	Standard deviation	7.46	1.63	0.72
	Range	5.10 – 7.34	2.92 – 3.89	0.95 – 2.15
Bread baking rate, kg/h	Mean	11.92	17.97	20.58
	Standard deviation	3.43	1.93	0.95
	Range	8.33 – 16.00	16.00 – 20.00	18.55 – 24.57

***** Current exchange rate: $ 1.00 = ₦ 127.60

Similarly, the change in the blood pressure and heart rate of subjects did not reach the lethal limits (Bodley, 1973; Aiyelari, Ndeay, & Hyuna, 1998) and therefore corroborated the earlier submission that bread-baking task is a light grade work.

3.4 Injury Magnitude

A total of 105 injuries were reported in the fifty bakeries visited during the period under review (Table 5). The highest cases of injury reported (27) involved the use of kneading/milling machine, representing 26% of the total reported cases. This was followed by brick oven (24), bread evacuator (18), and electric/gas oven (15). Other results are baking pan (12), mixer (6) and bun divider (3). In this study, 57 (54%) of injuries recorded were of A1S 2 class and above and were mainly due to kneading/milling machine, brick oven, electric/gas oven, and. In cases involving milling machines, about 6 cases of fingers amputation were reported. Severe burns were the results of accidents involving electric/gas /brick oven. These vary from minor burns to second-degree burns depending on the bread evacuator that caused the accident.

Table 4. Effects of fuel sources on environmental temperature and subjects' body temperatures, blood pressure and heart rate

		Sources of fuel		
		Wood	Gas	Electricity
Environmental temperature (^oC)	Mean	28.50	27.00	26.50
	SD	0.41	0.00	0.00
Change in body temperature (^oC)	Mean	1.50	1.01	0.72
	SD	0.42	0.52	0.31
Percentage change in blood pressure	Mean	1.0/14.9	1.04.4	1.0/5.8
	SD	0.0/8.2	2.2/2.8	2.2/6.4
Change in heart rate (BPM)	Mean change	7.75	5.65	6.50
	SD	3.30	2.70	2.92

SD – Standard deviation

Injuries involving bun divider, and mixer were of A1S 1 severity. Injuries caused by hand/fingers getting trapped in feed rollers were 20 (74%) in the 15-24 age group, 5 (19%) in the 25-34 age group and 2 (7%) among workers older than 35 years. Most of these cases resulted in amputation of fingers and hands, while others involved deep cuts and laceration. No injury was reported from mixer, kneading /milling machine, bun divider and baking in age group older than 44 years age. This could be attributed to length of service and acquired experience over time.

Table 5.Distribution of injuries by type of implement used and severity of injury

	Severity of injury					Total (%)
Implements	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	
Mixer	6	-	-	-	-	6 (6)
Kneading/milling machine	6	9	12	-	-	27 (26)
Bun divider	3	-	-	-	-	3 (3)
Baking pan	9	3	-	-	-	12 (11)
Electric/gas oven	6	6	3	-	-	15 (14)
Brick oven	12	9	3	-	-	24 (23)
Bread evacuator	6	6	6	-	-	18 (17)
Total (%)	48 (46)	33 (31)	24 (23)	-	-	105(100)

Table 6.Distribution of injuries by type of implement used and age of victim

Implements	Age (years)				Total (%)
	15 – 24	25 – 34	35 – 44	>44	
Mixer	5	1	-	-	6 (6)
Kneading/milling machine	20	5	2	-	27 (26)
Bun divider	2	1	-	-	3 (3)
Baking pan	8	3	1	-	12 (11)
Electric/gas oven	8	4	2	1	15 (14)
Brick oven	10	6	6	2	24 (23)
Bread Evacuator	10	4	3	1	18 (17)
Total (%)	63 (60)	24 (23)	14 (13)	4 (4)	105 (100)

As presented in Table 6, 87% of the recorded accidents involved workers below 34 years of age. This might be connected with the anxiety to achieve comparatively higher output at very short period of time and quest for quick money. A total of 63 injuries were reported for (15 – 24) year's age group with the highest cases (20) occurring due to the use of kneading/milling machine. This was followed by brick oven (10), bread evacuator (10), baking pan (8), electric/gas oven (8), mixer (5) and bun divider (2). 24 cases of injuries were reported for (25 – 34) year's age group with the highest occurrence due to the use of brick oven and the lowest due to both mixer and bun divider. For age group (35 – 44) years, 14 cases of injuries were reported out of which 6 were due to brick oven. Only 4 injuries occurred in subjects older than 44 years. One could notice the downward trend in the number of injuries as the ages of subjects increased. This shows that as bakery workers mature in age and years of experience, their ability to sustain injuries decreases.

4. CONCLUSIONS

The results of this study suggested that

(i) the highest energy requirement per unit quantity of baked bread was recorded in bakeries utilizing wood (6.15 KJ/min) followed by those using gas (3.37KJ/min) and electricity (1.52KJ/min) in that order.

(ii) The cost of energy per kg of baked bread was ₦7.58 with cooking gas as the energy source followed by ₦6.05 for electricity and ₦5.05 for wood in that order.

(iii) The average baking rate using firewood, gas and electricity as energy sources were respectively 11.92 kg/h, 17.97 kg/h and 20.58 kg/h, and

(iv) Analysis of metabolic data showed moderate (not to a lethal level) increase in the subjects' body temperatures, blood pressure and heart rates after baking operation.More than 80% of the injured were workers below 34 years of age.The study concluded that bread – baking operations are light grade work

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