Energy Optimization of Local Food Processing Industries in the North Central Nigeria

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Abstract- Types of energy source were identified in addition to unit operations/processes such as energy, time and number of persons and mass/material data were collected, computed and analyzed. Results showed no significant difference at 95% confidence level of the energy requirements for the 9 cases studied with respect to the identified unit process of operation of Gari production and the mean values of the total energy of consumption was found to be 1845.8MJ. Linear programming simplex method was used to minimize energy consumption in the local Gari production

Indexed Terms- Energy Requirement, Optimization, Gari, Wood fuel energy, Eenergy consumption,

I. INTRODUCTION

Effective energy utilization and energy source management in food processing facilities are desirable for reducing processing costs, conserving non-renewable energy resources, and reducing environmental impact. In recent time, there has been a greater awareness of the energy problems facing the world than at any other period in history (Wang, 2009). It is now widely accepted that the current rate of energy generation and supply cannot match the rapid growth in energy consumption rate (Aiyedun *et al*., 2008). The importance of energy in sustained economic development is a well-accepted fact.

The computation of energy use was done using the Microsoft Excel spreadsheet and energy accounting symbols presented by Singh (1986). A similar procedure for the breakdown of the *gari* production process into unit operations and determination of energy requirement in each was used. In Nigeria, energy auditing is not a wide spread practice, despite Nigeria through the Energy Commission of Nigeria has policy to that effect (Sambo, 2007).

Therefore, there has been no much literature on local *gari* processing in Nigeria especially in middle belt region. Therefore, the objective of this paper is to audit the energy utilization in the production of *gari* and developed energy conservation processing method.

The term energy audit is commonly used to describe a broad spectrum of energy studies ranging from a quick walkthrough of a facility to identify major problem areas to a comprehensive analysis of the implications of alternative energy efficiency measures sufficient to satisfy the financial criteria of sophisticated investors (Akpama, *et al*., 2009).

Energy audit is therefore, a review of the total energy used and costs, normally performed in conjunction with a site investigation. It involves the classification of the energy sources and their contribution in running the factory. It provides a structural review of how energy is being purchased, managed and used with the aim of identifying opportunities for energy cost saving through improved services. It also gives the estimate of potential annual energy savings with implementation costs and pay back periods.

Waheed *et al.,* (2008) energy and exergy studies were conducted in an orange juice manufacturing industry in Nigeria to determine the energy consumption pattern and methods of energy optimization in the company. An adaptation of the process analysis method of energy accounting was used to evaluate the energy requirement for each of the eight defined unit operations. The types of energy used in the manufacturing of orange juice were electrical, steam and manual with the respective proportions of 18.51%, 80.91% and 0.58% of the total energy. It was estimated that an average energy intensity of 1.12 MJ/kg was required for the manufacturing of orange juice.

Jekayinfa, (2007) carried out a study on energy audit of three poultry processing plants which was conducted in southwestern Nigeria. The plants were grouped into three different categories based on their production capacities. The survey involved all the five easily defined unit operations utilized by the poultry processing industry and the experimental design allowed the energy consumed in each unit operation to be measured.

1.1 Estimation of energy intensity (EI)

The energy intensity (energy consumed per unit product) for each of the unit operations (EI_i) required for the production of *gari* was estimated as the ratio of the sum of energy inputs per unit operation (Et_i) and the total weight of the product output (Hussein, 2011). It is expressed as:

$$EI_i = \frac{Sum\ of\ energy\ per\ unit\ operation\ ,Et_i(MJ)}{total\ weight\ of\ product\ output\ (kg)}$$

(Hussein, 2011) (1)

The average energy intensity (EI_{tt}) for the production of *Gari* was estimated as the ratio of the sum of energy inputs for all the unit operations (Et_{tt}) and the total weight of the product output. It is expressed as:

$$EI_{tt} = \frac{sum\ of\ energy\ inputs\ for\ all\ the\ unit\ operations\ ,\ \ Ett\ \ (MJ)}{total\ wieght\ of\ product\ output\ (kg)}$$

(Hussein, 2011) (2)

1.2 Estimation of energy productivity (EP)

The expression below was used to compute the value for energy productivity (Hussein, 2011).

$$Energy\ productivity\ = \frac{Processed\ Gari\ output\ (Kg)}{Energy\ input\ (MJ)}$$

(Hussein, 2011) (3)

1.3 Estimation of energy per unit product (EC/P)

The following expression by Hussein, 2011was used to compute energy cost per unit product

$$EC/P = \frac{Total\ Energy\ Cost*Energy\ Intensity}{Total\ Energy} \quad \text{(₦/kg)}$$

(Hussein, 2011) (4)

The energy cost was calculated for the different energy sources based on their respective rates and summed together.

1.3.1 Manual energy input

Manual energy estimation can be computed based on the value recommended by Odigboh (1999). According to Odigboh (1999) at the maximum continuous energy consumption rate 0.30kW and conversion efficiency of 25% the physical power output of a normal human labour in the tropical climates is approximately 0.075kW sustained for an 8 – 10 hours working day; all other factors affecting manual energy expenditure were found insignificantly and therefore neglected. To determine the manual energy for a given operation, the time spent by the worker on each operation was recorded. These include the intermittent resting periods. For any unit operation, the manual energy expenditure is as in equation 5 (Odigboh 1999).

$$E_{m=}\ 3.6(0.075N.T_a\ \ )(kWh) \qquad (5)$$

Where,

3.6 = conversion factor (1kWh = 3.6 MJ)

0.075 = the average power of a normal human labour in kW;

N = number of persons involved in the operation; and

T_a = useful time spent to accomplish a given task (operation), h.

1.3.2 Wood Fuel Energy Input

The energy demand (E) for operations utilizing fuel to run internal combustion engine is directly proportional to the quantity of fuel used (W), $E \propto W$, (Johnson, 1999 and Rajput, 2001).

$$E_w = C_f W \quad \text{(MJ)} \qquad (6)$$

Where, C_f, is the constant of proportionality which represents the calorific value (heating value) of fuel.

1.3.3 Fossil fuel energy input

Fossil fuel is a source of non-renewable energy. There are many examples of fossil fuels which we use in our daily lives. In fact, most of the energy that we consume is fossil fuels. Coal, petroleum, natural gas, these are all considered as fossil fuels. Many years ago, to be specific, during the carboniferous age, due to the change in atmospheric condition and other changes, there forests were destroyed and they were fossilized.

We are all using fossil fuels to meet up our daily energy needs. In fact, we have been using them at such a rate that it is predicted that these fossil fuels will become extinct in another 40-50 years. The two primary reasons why we need to clean energy sources are: - these fossil fuels are scarce resource and they cannot meet up demand for the generations to come and secondly these fossil fuels when burnt cause lot of air pollution.

$E_{FLD} = 47.8D, (MJ)$ (Ierve, 2012) (7)

Where E_{FLD} = liquid fuel energy input for diesel, MJ
47.8 = Unit energy value of diesel, MJL^{-1}
D = Amount of diesel fuel consumed per unit operation, (liter) (Ierve, 2012)

For Petrol, $MJ\ E_{LLP=}\ 42.3p\ (MJ)$ (7a)

Where E_{LLP} = liquid fuel energy input for petrol, MJ
42.3 = Unit value of petrol,
MJL^{-}P = Amount of petrol consumed per unit operation, (liter).

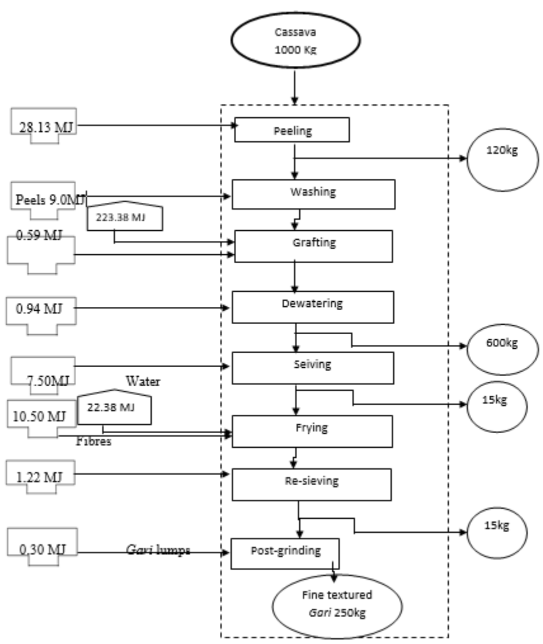

Figure 1: Energy flow Diagram in a Typical *Gari* Producing Mill
Source: Jekayinfa and Olajide (2007)

II. MATERIALS AND METHODS

The following apparatus/materials were used for this study:

a) Well-structured questionnaire: Designed and administered in each of the mills.
b) Knives: For peeling cassava.
c) Plastic and steel bowls: For washing the peeled cassava.
d) Grater: For grinding
e) Hydraulic press: For de-watering the grinded cassava.
f) Siever: For sieving the pressed products
g) Frying pan: For frying the sieved one.
h) Stop watch for measuring the production time;
i) Measuring cylinder**:** A 4 litre capacity constructed plastic tank used for measuring the quantity of fuel consumed in local mill.
j) Weighting bridge machine (Jahn rasper model): For weighting the quantity of cassava to be processed.
k) Microsoft excel software version 2007: For analyzing the raw data
l) Tora optimization software version 2.0 Optimization software: For optimizing the energy requirement.

2.1 Methods

2.1.1 Study area

Nine processing mills used for this survey are located in three Local Government Areas situated in Niger and Nassarawa States of Nigeria. These States are located in the North Central of Nigeria. The mills were selected to carry out the study because they are commercially viable. Table 1 presents details of the sites and locations.

TABLE 1: LOCATIONS AND CASES STUDIED

S/No	Location	Case 1	Case 2	Case 3
1	Borgu L.G.A. Niger State	New Army barracks Kainji	Old Army barracks Kainji	New Bussa Township
2	Keffi L.G.A. Nassarawa State	Angwan Kwanu	Army barracks	Angwan Sarki Mada
3	Kokona L.G.A Nasarawa State	Dare	Basa	Kasuwan Gwari

2.2 Data Collection

Data for quantification of energy used for each unit operation of processing *gari* were collected from nine *gari* processing mills. Methodology used included on-site study of all unit operations in the industries, administration of structured questionnaire and oral interview of processors and their workers.

Data of required parameters for evaluating energy input in *gari* production was then compiled for all the cases. For the raw data of this operation, see Appendix 1A where the calorific value of fire wood fuel used is 16.6MJ/Kg (air dry and dry zone) which was obtained from Appendix IXA, B, C, D, E, F, G, H, I, J, K, L. while the calorific value of fuel used was 47.8 MJ/L for diesel using equations 3.

TABLE 2: MEASURED PARAMETERS FOR ESTIMATING ENERGY INPUT INTO *GARI* PROCESSING PLANT

S/N	Process	Required parameters
1	Peeling	Time taken for peeling (h) Number of persons involved
2	Washing	Time taken for Washing (h) Number of persons involved
3	Grating	Time taken for Grating (h) Number of persons involved Quantity of fuel used (L) Calorific value of diesel fuel (MJ/L)
4	Pressing	Time taken for Pressing (h) Number of persons involved
5	Sieving	Time taken for Sieving (h) Number of persons involved
6	Frying	Time taken for Drying (h) Number of persons involved Quantity of fuel used (L) Calorific value of Wood fuel used (MJ/L)
7	Re – sieving	Time taken for Re- Sieving (h) Number of persons involved

III. EXPERIMENTAL PROCEDURE

The primary energy resources utilized in the plant were identified to be manual (obtained from human labour), liquid fuel energy (obtained from fossil fuel), and wood fuel energy (obtained from wood fuel). Seven unit operations were defined for *gari* production process: peeling, washing, grating, dewatering, sieving, frying and re-sieving.

The energy analysis was based on process analysis in which the direct energy consumption in every successive production step was estimated and the materials in put to each operation also indicated. These raw data were then converted to energy equivalent using developed energy equations (5), (6), and (7).

3.1 Data Analysis

From the data collected, the following procedural steps were taken to get them analyzed and presented in the required forms:

- Energy types (manual, liquid fuel and wood fuel) were identified and collated
- The percentage breakdown of total consumption and cost by energy type was calculated.

- The average overall cost per MJ of each energy type per operation was determined to establish relative significance.
- Tables were prepared for each section showing total consumption and cost for each energy type.

3.1.1 Statistical analysis

All the experimental procedures were repeated thrice. Mean values were recorded as data obtained. The data for both energy and cost of the nine cases was subjected to two way analysis of variance (ANOVA) without replica using excel 2007, to test for the significance difference.

3.1.2 Total energy input

The total energy expended in producing *gari in* each mill was evaluated by summing up all the energy components involved in the process.

Thus the total energy was computed using the following expression

$$E_T = E_p + E_w + E_g + E_d + E_s + E_f + E_r \quad (17)$$

IV. RESULTS

Mean result of production cost for the entire study is presented in Tables 3 - 6.Result of mean energy used sources and production is presented in Table 7.

TABLE 3: OPTIMAL SOLUTION OF LINEAR PROGRAMMING MODEL FOR COST OF ENERGY OPTIMIZATION OF *GARI* PRODUCTION

Final Iteration No. 7

Objective value = ₦3177.47

Variables	Solution Value	Objective Coefficient	Objective Value Contribution
x_1	0.0’0	432.36	0.00
x_2	0.00	368.48	0.00
x_3	0.98	931.13	912.87
x_4	0.00	42.34	0.00
x_5	0.00	139.75	0.00
x_6	1.11	2038.14	2264.6
x_7	0.00	52.33	0.00

TABLE 4: CONSTRAINTS OF THE ENERGY COST

Constraints	Right Hand Side (RHS)	Slacks-/Surplus+
1 (>)	10.00	1.96+
2 (>)	1800.00	170.56+
3 (>)	5.00	0.00
4 (>)	100.00	0.00

TABLE 5: SENSITIVITY ANALYSIS OF OBJECTIVE FUNCTION’S COEFFICIENT OF ENERGY COST

Decision Variable	Current Objective Function	Minimum Objective Function	Maximum Objective Function	Reduced Cost
x_1	432.36	0.00	Infinity	-432.36
x_2	368.48	0.00	Infinity	-368.48
x_3	931.13	0.00	Infinity	0.00
x_4	42.34	0.00	Infinity	-42.34
x_5	139.75	0.00	Infinity	-139.75
x_6	2038.14	0.00	Infinity	0.00
x_7	52.33	0.00	Infinity	-52.33

TABLE 6: SENSITIVITY ANALYSIS OF RIGHT HAND SIDES (RHS)

Constraint	Current RHS	Minimum RHS	Maximum RHS	Dual Price
1 (>)	10.00	Infinity	11.96	0.00
2 (>)	1800.00	Infinity	1970.56	0.00
3 (>)	5.00	1.76	Infinity	182.57
4 (>)	100.00	90.00	Infinity	22.65

TABLE 7: MEAN ENERGY USE CHARACTERISTICS AND PRODUCTION IN *GARI* MILLS STUDIED

Loc./Cases	*Gari* Output (kg)	Manual Energy (M J)	Liquid fuel energy (MJ)	Wood fuel energy (MJ)	Total energy (MJ)	% share of manual	% share of liquid fuel	% share of wood fuel	Energy intensity Ei (MJ/kg)	Energy productivity Ep (kg/MJ)	Energy cost per unit product Ecp (₦)
Location 1											
Case 1	255	57.18	243.78	1494	1794.96	3.19	13.58	83.27	7.0	0.14	15.58
Case 2	250	53.06	318.83	1411	1782.89	2.98	17.88	79.14	7.1	0.14	15.69
Case 3	255	57.71	239	1660	1956.71	2.94	12.22	84.84	7.7	0.13	15.86
Mean	253.3	56.0	267.2	1521.7	1844.9	3.0	14.6	82.4	7.3	0.14	15.7
Location 2											
Case 1	257	65.34	286.8	1477.4	1829.54	3.57	15.67	80.75	7.1	0.14	16.07
Case 2	260	57.87	310.7	1577	1945.57	2.97	15.97	81.06	7.5	0.13	16.21
Case 3	250	61.77	244.18	1693.2	1999.15	3.09	12.22	84.69	7.9	0.13	16.18
Mean	255.7	61.7	280.6	1582.5	1924.8	3.2	14.6	82.2	7.5	0.13	16.2
Location 3											
Case 1	258	66.19	229.44	1460.8	1756.43	3.76	13.07	83.17	6.8	0.15	15.18
Case 2	254	60.72	234.22	1480.72	1775.66	4.84	13	82.16	7.0	0.14	15.2
Case 3	255	61.33	234.22	1471.08	1769.73	3.47	13.24	83.29	6.9	0.14	14.92
Mean	255.7	62.8	232.7	1470.9	1767.7	4.0	13.1	82.9	6.9	0.14	15.1
Mean Study	255.7	60.7	260.2	1525.0	1845.8	3.4	14.1	82.5	7.2	0.14	15.7

V. DISCUSSION

5.1 Energy Requirement for Production of *Gari*.

The average energy requirement at different stages of *gari* production process in all the three locations investigated is presented in Table 6 and Figure 3. These represent the energy consumption pattern for production of *gari*. In the locations considered and at the time of this study, wood fuel energy was the most used energy source, followed by liquid fuel energy and manual energy. This shows that all the mills extensively use wood fuel for operation. 82.80% of the average total energy in all the three locations was obtained from wood fuel source, followed by 14.40% and 3.10% from liquid fuel and manual energy sources respectively.

The average energy used for frying (1536.32MJ) was the highest accounting for 82.80% of the total energy consumption. This was followed by grating (268.81MJ, 14.50%), peeling (27.67MJ, 1.40%), washing (9.48MJ, 0.50%), sieving (7.96MJ, 0.43%), re-sieving (2.56MJ, 0.08%), dewatering (1.69MJ, 0.08%). Conclusively the average energy required for processing 1000kg mean raw material input into *gari* was 1853.82MJ.

5.1.2 Energy cost analysis of variance (ANOVA)

Result of Analysis of variance (ANOVA) at 5% level presented in Table 11 shows that there was a significant difference in the production cost of the nine cases at 95% confidence level. The difference could be due to variation in the prices of wood fuel, liquid fuel, quantity of fuel consumed, and the number of persons employed to manual labour at the various locations.

5.2 Analysis of Variance (ANOVA) of Energy Requirement

Before the running the observed energy regression model of *gari* production in the study, analysis of variance (ANOVA) at 5% significant difference was conducted for the 9 cases for the energy requirement and the different unit operations for the production of *gari* as presented in Table 3.There was no significant difference in the energy requirements for all the 9 cases at 95% confidence level meaning the system has been standardized. The mean values therefore became consequential to be employed for optimization but there was significant difference for the different energy types employed in *gari* production in the same analysis.

5.2.1 Model equation for estimating energy requirement of unit operations

The model equations are presented in Table 5 both linear, log linear, polynomial and exponential model were tried. The selection of the equation was based on the value of R^2. The equations have R^2 value of 0.7 that best explains the relationship between energy and material input for the various unit operations except frying that has a weaker correlation $R^2 < 0.5$. The unexplained variation could be due to unforeseen parameters like age of equipment, age and experience of workers and maturity.

5.3 Energy productivity (EP)

The highest energy intensity of (0.14kg/MJ) was recorded in locations 1 and 2 followed by 0.13kg/MJ in location 3. The variation was because the system is localized. The average cost per unit product was 0.14kg/MJ.

5.4 Energy cost per unit product (EC/P)

The highest cost of energy per unit product of (₦16.20) was recorded in location 2, followed by (₦15.70) location 1 and (₦15.10) in location 3. The variation was because the system is localized. The average cost per unit product was (₦15.7).

CONCLUSION

In this research, the energy efficiency and optimization of *gari* production was examined. Seven defined unit operations were established for the production of *gari*: peeling, washing, grating, dewatering, sieving, frying and re-sieving. Manual, wood fuel and liquid fuel energy were the main source of energy input in *gari* processing industries.

1. The ANOVA showed no significant difference at 95% confidence level implying that the system is standardized. The prediction equations gave very high values of total energy involved and energy requirements in relation to unit operations. This means that future energy requirement can be predicted by these equations.
2. The energy efficiency indices: energy intensity, energy productivity and energy cost per unit productivity for the three locations varied because the system is localized.

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