Energetic Analysis of Poultry Processing Operations

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Abstract

Energy audit of three poultry processing plants 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. The results of the audit revealed that scalding & defeathering is the most energy intensive unit operation in all the three plant categories, averagely accounting for about 44% of the total energy consumption in the processing plants. Other processing operations consuming energy in the following order are eviscerating (17.5%), slaughtering (17%), washing & chilling (16%) and packing (6%). The results of the study clearly indicated that the least mechanized of the plants consumed the highest energy (50.36 MJ) followed by the semi-mechanized plant (28.04 MJ) and the most mechanized plant (17.83 MJ). The energy audits have provided baseline information needed for carrying out budgeting, forecasting energy requirements and planning plant expansion in the poultry processing industries in the study area.

Keywords

Poultry processing, energy requirement, unit operations, production capacity

Introduction

Following the ban on the importation of poultry products by the Federal Government of Nigeria as policy measures to revive the economy and encourage the local poultry farmers, there has been an increase in the number of poultry processing plants in the country. A poultry processing plant is an integral part of an extensive poultry-farming venture comprising also the breeder flocks, hatchery, feed mill, broiler flocks and other related services. These areas of poultry business are mostly owned and controlled by a single organization. Poultry processing consists of five easily defined unit operations (Figure 1): slaughtering, scalding & defeathering, eviscerating, washing & chilling and packaging. All these process operations require energy in one form or the other, either as fossil fuel, electricity or human labour. Electricity is used for refrigeration, lighting, air conditioning and other mechanical drives. Fossil fuels are used for production of hot water for defeathering operation.

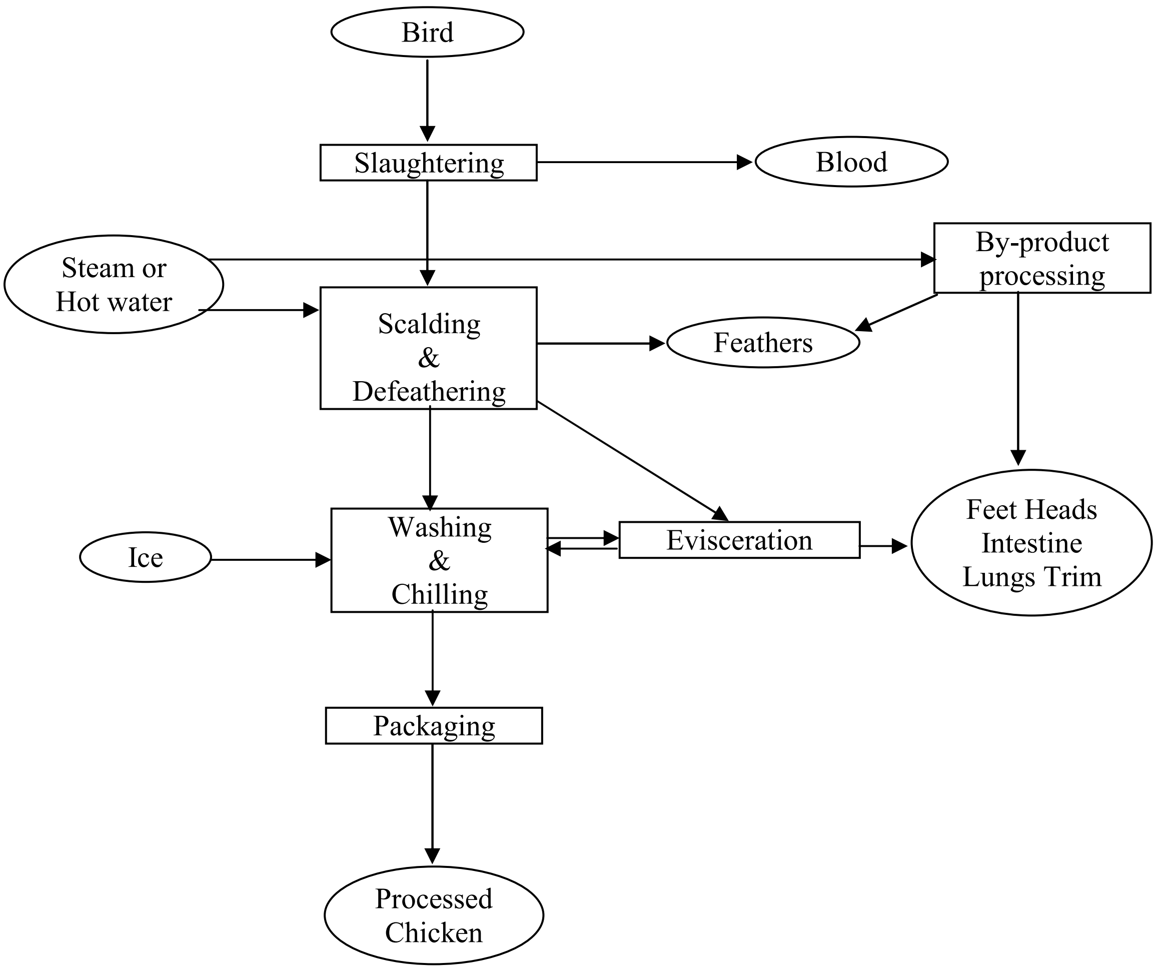

Figure 1. Flow diagram of poultry processing

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The actual significance of energy costs in a particular processing industry is dependent on the type of products manufactured, the processing methods adopted and the relative price of energy. The primary objective of any energy management scheme is to minimize the energy cost component of the production costs, but not at the expense of product quality or higher overall costs (Miller, 1986). Energy is one of the largest components of the production cost and the efficiency of its use will often be compromised in favour of other equally important factors. The need for such great attention to energy management has been highlighted by several published surveys of energy use in agricultural processing operations. These include: palm kernel oil processing (Jekayinfa, 2004; Jekayinfa, & Bamgboye, 2004), cashew-nut processing (Jekayinfa, & Bamgboye, 2003; Jekayinfa, & Bamgboye, 2005), vegetable canneries (Vergara, Rao & Jordan, 1976), tobacco curing (Cundiff, & Dodd, 1981), rice processing (Ezeike, 1981; Verma, 2002), sunflower oil expression (Farsaie & Singh, 1985), milk processing (Harris, 1982; Elsy, 1980 & Wilhem, Suter & Brusewitz, 2004), poultry processing in USA (Whitehead & Shupe, 1979; Baughman & Parkhurst, 1977 & USDC, 1993).

Very few processing factories have any precise idea of the energy consumption of different production areas and in the absence of detailed internal monitoring; the energy efficiencies of different operations are also usually unknown. The knowledge of energy consumption in each unit operation of a production system is useful for determining high-energy consuming areas. These areas can only be identified by methodological energy analysis of all processing operations. Energy analysis allows the energy cost of existing process operations to be compared with that of new or modified production lines. It also enables a plant operator to compare his energy efficiency with that of a competitor or with that of another factory within the same company. Finally, the knowledge of energy consumption for each product in a factory is useful for several purposes such as budgeting, evaluation of energy consumption for a given product, forecasting energy requirement in a plant, and for planning plant expansion.

There is no known report in the literature on the energy requirements of poultry processing operations as practiced in Nigeria. 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 present study is to estimate energy requirement in the eight readily defined poultry processing operations as practiced in Nigeria. The study will provide an opportunity for having a reliable database concerning consumption of various types of energy by different users in poultry processing ventures. It will also provide a firm basis of identifying options for saving energy in poultry process operations.

Plant description

The three poultry processing plants selected for case studies represent typical operations in the Southwestern part of Nigeria. The energy data collected do not however represent an industry average or normal. The characteristics of the three plant categories are discussed below:

Category 1: This is regarded as the small size plant that processes at a rate of 10,000-processed chicken per day.

Category II: This plant, categorized as a medium single-shift plant, has a production rate of 20,000 birds per day.

Category III: This is categorized as large plant with a production rate of 30,000 chickens per day.

The processing techniques and facilities of all the three plants differ, as do the type and make of equipment, and the degree of mechanization of operations.

Processing technology of poultry and methods of energy evaluation

Poultry undergoes some sequential processing operations, which convert it to the final primary product known as chicken. The sequence of poultry operations common in the three plants surveyed is outline in Figure 1. At each stage of the unit operations, some level of energy input is required in the form of electrical energy, thermal energy and human energy. The type and magnitude of the energy consumed is a function of the technology employed and the number of birds being processed. In order to quantify the energy demands of each unit operation, quantitative data on operating conditions would be required for each unit operation.

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Table 1 summarizes the production technologies under study in the three poultry processing plants.

Table 1. Measured parameters for evaluating energy input data in poultry processing plants

S/N	Operation	Required parameters
1.	Slaughtering	• Electrical power, kW • Fuel consumed, *l* • Calorific value of fuel used, J/*l* • Time taken for drying, h • Number of persons involved in cleaning
2.	Scalding & defeathering	• Electrical power, kW • Fuel consumed, *l* • Calorific value of fuel used, J/*l* • Time taken for soaked, h • Number of persons involved in soaking or conditioning
3	Eviscerating	• Electrical power, kW • Fuel consumed, *l* • Calorific value of fuel used, J/*l* • Time taken for roasting, h • Number of persons involved in roasting
4.	Washing & chilling	• Electrical power, kW • Fuel consumed, *l* • Calorific value of fuel used, J/*l* • Time taken for shelling, h • Number of persons involved in shelling
5.	Packaging	• Electrical power, kW • Fuel consumed, *l* • Calorific value of fuel used, J/*l* • Time taken for kernel separation, h • Number of persons involved in separation

The types and magnitudes of the parameters required for the energy evaluation of each unit operation are presented in Table 2.

Ezeike (1981) and Jekayinfa and Bamgboye (2003, 2005) have used similar procedure in the energy audits of rice processing mills, palm-kernel oil mills and cashew-nut mills in Nigeria. The energy evaluation method for each unit operation follows:

Slaughtering

The process of poultry processing begins by removing feeders the night before birds are to be dressed. This empties the gut and reduces fecal contamination if the intestines are cut during evisceration.

Table 2. Processing techniques at the three poultry processing plants

S/N	Operation	Equipment and principle adopted		
		Plant A	Plant B	Plant C
1.	Slaughtering Manual killing	Manual with cone killing stand and stunner/sticking knife	Semi automated with stunner/sticking knife	Motorized with complete hanging/sticking/bleeding equipment comprising: loading bar, overhead conveyor for killing and bleeding out, shackles and bleeding trough
2.	Scalding & Defeathering	Manual with holding table, bowl, plucker feather bins and mobile racks	Semi automated incorporating a wet scald system with pin feathers remover and dry plucking machine	Motorized with flight feather remover, feather bins and pinning table or finisher
3.	Evisceration	Manual with an over head rail, carousel or table	Manual with an overhead rail and carousel or table	Evisceration unit comprising conveyor line, shackles, evisceration trough and mobile offal track. Giblet processing unit and Gizzard skinner
4.	Washing & chilling	Carcases are spray-washed and chilled rapidly before packaging	Semi automated with carcase washer and sink unit	Semi automated with ice tank or spiral washer chiller
5.	Packaging	Manual	Manual	Semi automated by over-wrapping and bag wrapping

Two main methods are employed; manual method and automated method. In the manual method, the bird is held in a small cloth bag that has a very small part of one corner cut off. The head and neck are thereafter drawn through the hole in the corner and the neck is cut through the earlobe from top to bottom with a swift from stroke of the knife. The automated method involves the use of a stunner/sticking knife. The energy consumed per 1000 birds is obtained from the expression.

$$E_s = 3.6\ [k_s P_s t_s + 0.075\ N_s t_s] \tag{1a}$$

when electricity is used or

$$E_s = W_s C_s + 3.6\ [0.075\ N_s t_s] \tag{1b}$$

when I.C. engine is used or

$$E_s = 3.6\ [k_s P_s t_s + 0.075\ N_{ss} t_s] + W_s C_s \tag{1c}$$

when both electricity and I.C. engine are used or

$$E_s = 3.6\ [0.075\ N_s t_s] \tag{1d}$$

when poultry processing is totally carried out manually; where 3.6 = Conversion factor (1 kWh = 3.6 MJ), and 0.075 = the average power of a normal human labour, kW.

Scalding and defeathering

The scald water is prepared at 138 - 140°F. In the manual method of scalding, the bird is held by the feet and its head is plunged first into the scald water. The bird is kept fully submerged in the scald water while it is worked up and down to get the water well under the feathers for about 1 - 3 minutes. The scalded bird is re hung or placed on a table top, where the main wing and tail feathers are pulled first. Thereafter the body feathers are plucked by pulling against the grain. This process required speed while the carcass is warm. To remove the pinfeathers, a table knife is employed. The automated method comprises an electric motor driving a shaft supported by a bearing assembly. The plucking head, driven by a belt, consists of a series of rotating plates held at an angle by a thrust plate at each end of the plate bearing. As the discs rotate they come together, drag in the feathers, grip them and pull them from the bird. As the discs continue to rotate, they separate, and release the feathers into a collection bag to the rear of the machine. The energy consumed for scalding & defeathering per 1000 birds is obtained from the expression:

$$E_{sd} = 3.6\,[k_{sd} P_{sd} t_{sd} + 0.075\, N_{sd} t_{sd}] \quad (2a)$$

when electricity is used or

$$E_{sd} = W_{sd} C_{sd} + 3.6\,[0.075\, N_{sd}\, t_{sd}] \quad (2b)$$

when I.C. engine is used or

$$E_{sd} = 3.6\,[k_{sd} P_{sd}\, t_{sd} + 0.075\, N_{sd}\, t_{sd}] + W_{sd} C_{sd} \quad (2c)$$

when both electricity and I.C. engine are used or

$$E_{sd} = 3.6\,[0.075\, N_{sd}\, t_{sd}] \quad (2d)$$

when scalding & defeathering is totally carried out manually.

Evisceration

The carcass is hung by the feet and the defeathered bird is cut around the neck at the base of the head. The head is then twisted and pulled off and other internal organs removed. The automated method involves the use of machinery that is able to slit the necks, detaching from crop and depositing into evisceration through. It also involves: Cutting round vents and opening aperture, drawing out viscera but leaving it attached to the carcass, removing liver, hearts and gizzards and placing them in the appropriate giblet trays, detaching inedible offal and allowing it to fall into the evisceration trough.

The energy consumed for eviscerating 1000 birds is obtained from the expression:

$$Ee = 3.6\ [ke\ Pe\ te + 0.075\ Ne\ te] \quad (3a)$$

when electricity is used or

$$Ee = We\ Ce + 3.6\ [0.075\ Ne\ te] \quad (3b)$$

when I.C. engine is used or

$$Ee = 3.6\ [ke\ Pe\ te + 0.075\ Ne\ te] + We\ Ce \quad (3c)$$

when both electricity and I.C. engine are used or

$$Ec = 3.6\ [0.075\ Nc\ tc] \quad (3d)$$

when is totally carried out manually.

Washing & Chilling

A mechanized washing device followed eventually by chilling often complements a continuous flow process. Such devices are often motorized and consume energy for the period they are in operation whether motorized or otherwise, the energy component can be quantified by use of the expression:

$$Ewc = 3.6\ [kwc\ Pwc\ twc + 0.075\ Nwc\ twc] \quad (4a)$$

when electricity is used or

$$Ewc = Wwc\ Cwc + 3.6\ [0.075\ Nwc\ twc] \quad (4b)$$

when I.C. engine is used or

$$Ewc = 3.6\ [kwc\ Pwc\ twc + 0.075\ Nwc\ twc] + Wwc\ Cwc \quad (4c)$$

when both electricity and I.C. engine are used or

$$Ewc = 3.6\ [0.075\ Nwc\ twc] \quad (4d)$$

when washing & chilling is totally carried out manually.

Packaging

Another major source of energy consumption is the packaging of processed chicken before they are frozen or transported for sales. When mechanical packing device is utilized, either fuel or electrical energy is consumed. In plants where this operation is totally done manually, energy is also consumed. Thus the energy consumption for packing operation can be expressed as:

$$Ep = 3.6\ [kp\ Pp\ tp + 0.075\ Np\ tp] \quad (5a)$$

when electricity is used or

$$Ep = Wp\ Cp + 3.6\ [0.075\ Np\ tp] \quad (5b)$$

when I.C. engine is used or

$$Ep = 3.6\ [kp\ Pp\ tp + 0.075\ Np\ tp] + Wp\ Cp \quad (5c)$$

when both electricity and I.C. engine are used or

$$Ep = 3.6\ [0.075\ Np\ tp] \quad (5d)$$

when poultry packing operation is totally carried out manually.

Total Energy Requirement

The total energy requirement for processing any quantity of poultry is the sum of the energy components involved in each process. Thus the total energy ET becomes:

$$ET = Es + Esd + Ee + Ewc + Ep \quad (6)$$

With eq 6, it is possible to determine the total energy consumed in the plant processing poultry at a given production rate.

Methodology

The estimation of energy requirements in the 5 major unit operations of poultry processing involved the use of spreadsheet program on Microsoft Excel. This makes the computational procedure easy to follow by any plant operators desiring to compute the energy consumption pattern of their processing operations at any accounting period. The parameters (Table 2) contained in Eqs 1 - 6 were measured using the following assumptions.

- A motor efficiency of 75 per cent was assumed for all the motors used to compute the electrical inputs
- A value of 0.075kW was used to compute the human energy expenditure in all unit operations. This value represents the average power a normal human labour can supply in tropical climates (Megbowon & Adewunmi, 2002).
- Fuel energy and electrical energy were converted to common energy unit using conversion factor of 3.6 MJ/ kWh (Whitehead & Shupe, 1979).

All the mills selected were evaluated over the same period and seasons, and as a result, the error of seasonal changes was eliminated. No prior experimental conditions were used as data collection in each locality was done as the mills were in operation. All the mills were less than ten years old to ensure that they were within their useful years. The apparatus used for the study include:

- A stop watch for measuring production time
- A measuring cylinder for quantifying the amount of fuel consumed during each unit operation.

The error analysis was done using the following equation

$$error = (measured\ value - true\ value)/(true\ value)*100 \quad (7)$$

Results and Discussion

Energy utilization (Table 3) among the plants with respect to the major unit operations was generally very similar with only some noticeable differences.

The portion of the total energy use required for slaughtering facilities averaged 16.97% (Figure 2).

Consumption of electrical energy for slaughtering ranged between 4.53 and 5.54 MJ. Manual energy consumption ranged between 2.03 and 5.81 MJ. Plant C used much more energy for slaughtering because of its larger slaughtering device that operated more hours per day and because of the higher level of sophistication of its slaughtering facilities that consumed more electrical energy. Energy consumption increased from Plant A to Plant B and Plant C in that order.

The average energy use in the scalding & defeathering area of the three poultry processing plants was 44% of the total. This translates to an average energy consumption of 15.05 MJ ranging from 6.08 to 26.20 MJ. The electrical energy consumption ranged from 5.54 to 24.17 MJ, with most of this being used for the scalders. The manual energy use for scalding & defeathering ranged between 0.54 and 2.03 MJ. Thus, the total energy requirement for carrying out scalding & defeathering operation for 1000 birds are 26.20 MJ, 12.88 MJ and 6.08 MJ in plant A, plant B and plant C respectively.

Table 3. Calculated energy use (MJ) from different sources for major unit operations in three poultry processing plants

Unit operations	**Plant A** 10,000 birds/day	**Plant B** 20,000 birds/day	**Plant C** 30,000 birds/day
Slaughtering			
Electrical energy	-	5.54	4.53
Manual energy	2.03	0.27	0.14
Total energy	2.03	5.81	4.67
Scalding & defeathering			
Electrical energy	24.17	12.34	5.54
Manual energy	2.03	0.54	0.54
Total energy	26.20	12.88	6.08
Evisceration			
Electrical energy	-	3.54	2.63
Manual energy	10.05	0.54	0.54
Total energy	10.05	4.08	3.17
Washing & Chilling			
Electrical energy	-	3.05	2.05
Manual energy	10.05	0.54	0.54
Total energy	10.05	3.59	2.59
Packaging			
Electrical energy	-	1.14	1.05
Manual energy	2.03	0.54	0.27
Total energy	2.03	1.68	1.32
GRAND TOTAL	**50.36**	**28.04**	**17.83**

Evisceration averagely accounted for 17.44% of the total energy requirement per 1000 birds in the three poultry processing plants, the values ranging from 3.17 MJ in plant C to 10.05 MJ in plant A. Out of the energy portion used for evisceration, 100% (10.05); 13.2% (4.08 MJ) and 17% (3.17 MJ) can be attributed to human labour in plant A, Plant B and Plant C respectively. It is worth noting that these energy consumption for evisceration does not include electricity used for further intestine processing. Washing & chilling used 15.75% of the total energy, about 6.26 MJ/1000 heads; but this does not include refrigeration for storage areas. The manual energy consumption for washing & chilling ranged from 0.54 to 10.05 MJ Packaging accounted for the least portion (5.8%) of the total energy consumption in the three poultry processing plants with values ranging between 1.32 MJ in plant C and 2.03 MJ in plant A. Out of this energy consumption, 100% was used as manual energy in plant A, 32% in plant B and 20.5% in plant C.

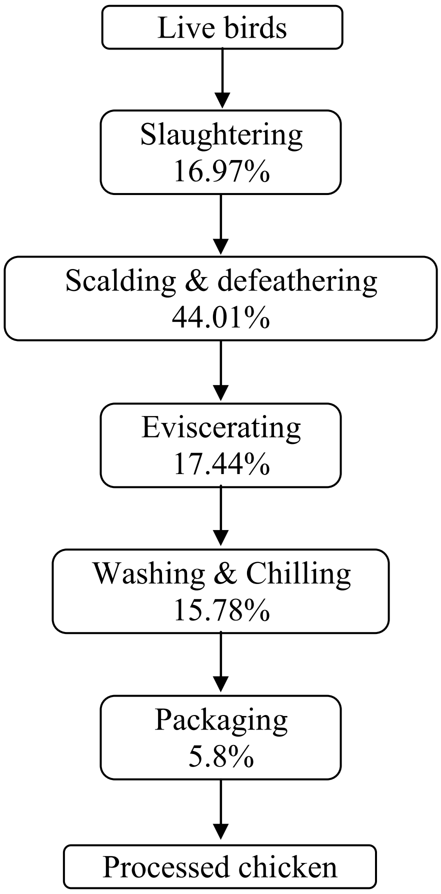

Figure 2. Average energy use (percent of total) for the unit operations in three poultry processing

As can be observed in Table 3, there are variations in the amounts of energy used by the three plants for the different unit operations. This indicates that each plant could affect savings by altering or changing process operations. The results of the study clearly indicate that plant A, which is the least mechanized of the 3 plants, consumed the highest energy (50.36 MJ) followed by plant B (28.04 MJ) and plant C (17.83 MJ) in that order. This shows that plant A used 3 times and 2 times as much energy as plant C and plant B respectively because of its high energy consuming facilities which are not only rudimentary but almost becoming obsolete. The data show that the developed equations were adequate for estimating the energy requirements in poultry processing operations. For instance, for the estimation of total energy in plant A, the means value of errors between the measured value and true value was 0.108. The Standard Deviation of the differences was 0.135 with a worst-case error of 0.02. Similar data for plant B and plant C were 0.338, 0.216, 0.05 and 0.252, 0.255, 0.04 respectively. Average energy consumption in the three plants is schematically represented in Figure 3.

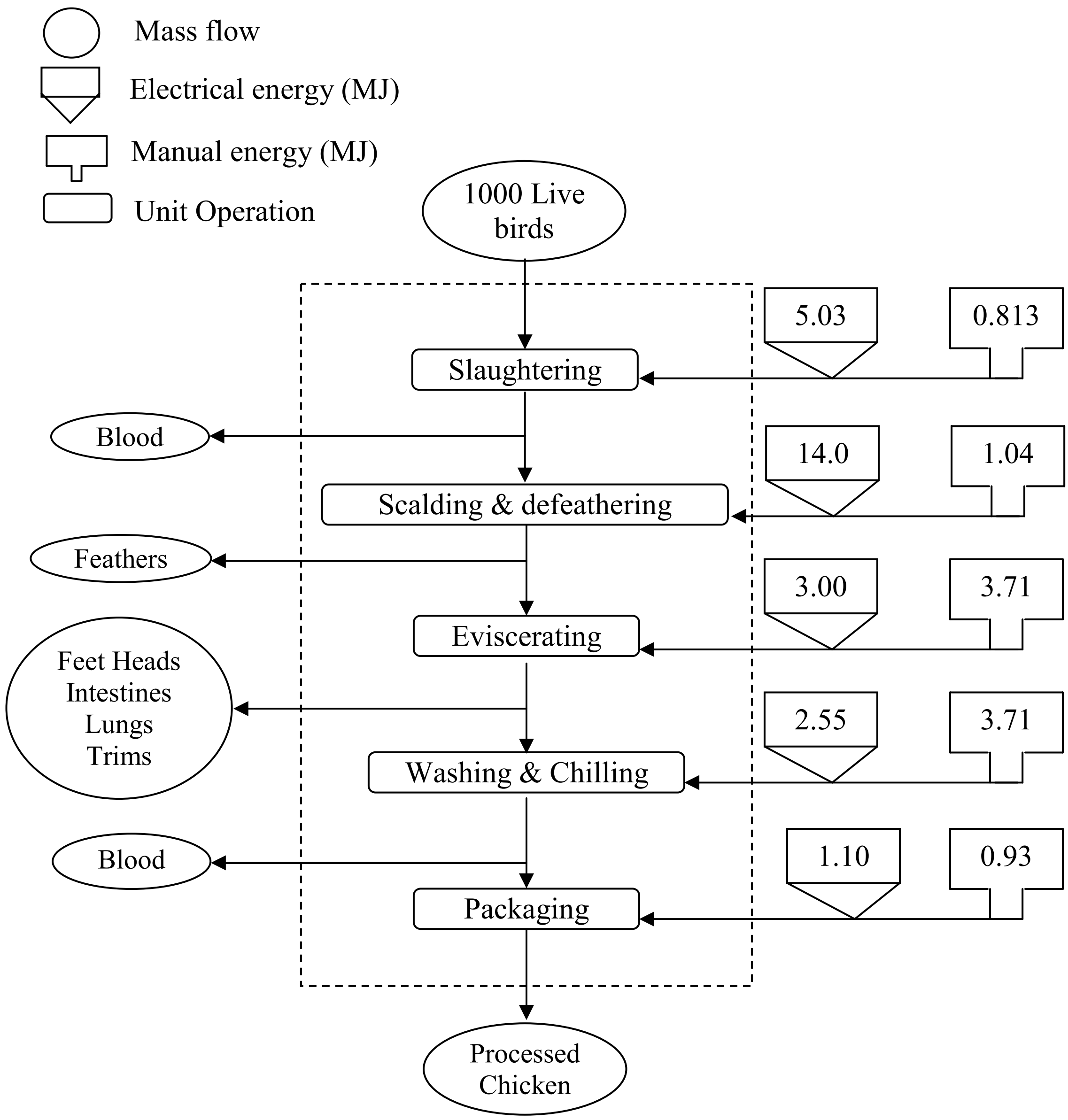

Figure 3.Energy (average) flow diagram in the three poultry processing plant

It is also worth mentioning that electricity consumption in all the plants could have been reduced if supply from the national grid has been constant. The fluctuation in electricity supply was so intense during the period this research lasted that owning a processing outfit was not complete without the procurement of a stand-by generator. Quite a sizeable amount of energy savings could have been achieved if the report of Megbowon and Adewunmi (2002) is any thing to go by. According to the report, 30% of expenditure could be saved if electricity supply from the National grid is always available in agro-based companies. The capital invested for the acquisition of generators and the associated maintenance cost could have better been utilized for the procurement of more raw materials, more efficient equipment and expansion of the business. The usual effect, as noticed in some poultry processing plants visited during the preliminary investigation, is that the growth of the company is slowed down and the burden of high cost of production is passed to the consumers, who are already overstressed.

The monthly energy use in each plant and their total over seven accounting months are shown in Figure 4.

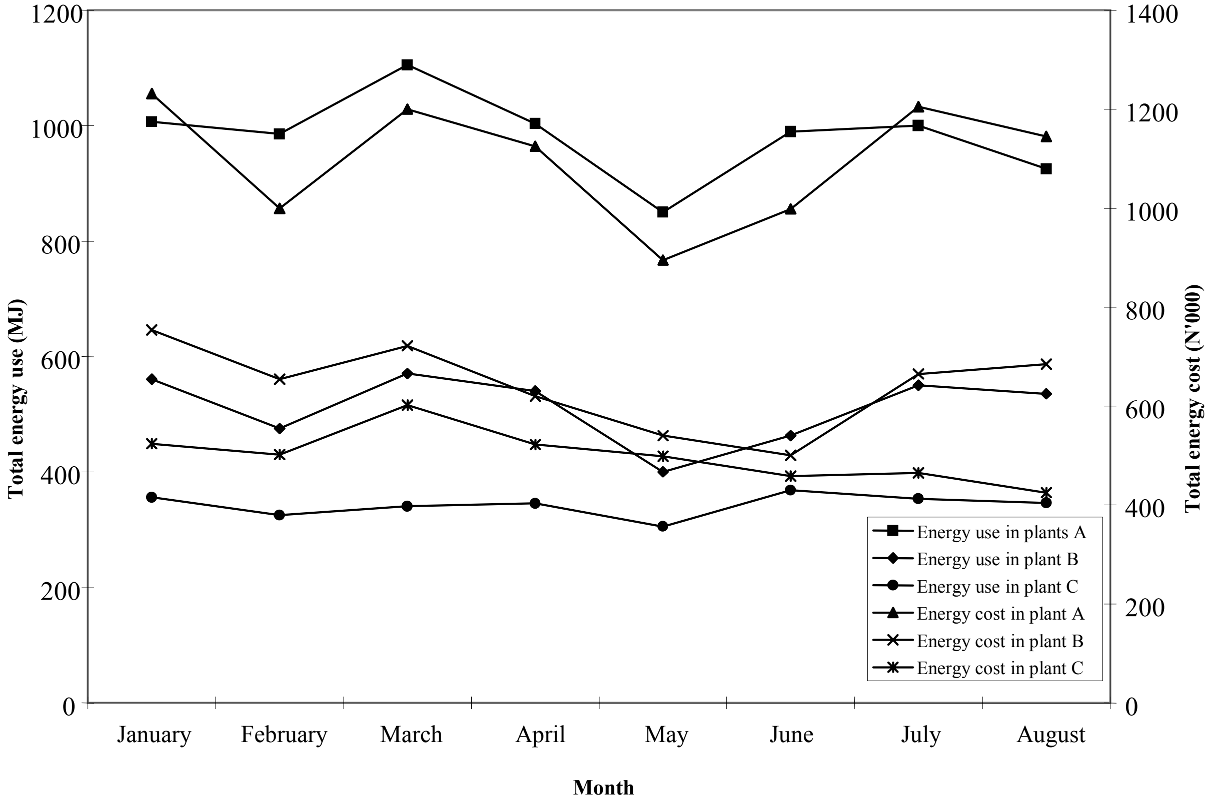

Figure 4. Trends in energy use and energy cost of three poultry processing plants in Nigeria

Monthly energy cost is also superimposed on the figure. Over the duration that data was gathered, the sum of energy consumption in all the plants was directly proportional to energy cost.

These trends are explained by the relatively stable prices of petroleum products and electricity during the accounting period unlike in earlier years, when there were shortages in the local refining of petroleum products and there were four upward reviews of petroleum products within a year in Nigeria.

This finding has also been corroborated by the reports of Megbowon and Adewumi (2002) and Jekayinfa (2004).

Conclusions

The energy audit of the selected poultry processing plants revealed that electricity obtained either from the national grid or captive generated, is the main source of energy input for poultry processing operations. It was also observed that the total energy requirement per 1000 birds in the three selected plants is respectively 50.36MJ, 28.04MJ and 17.83MJ. In all the plants, scalding of defeathering accounted for 44% of the total energy consumption followed by eviscerating, slaughtering, washing & chilling and packing in that order. The results of the study have provided useful information for carrying out budgeting, forecasting energy requirements and planning plant expansion.

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Nomenclature

Es	Energy requirement for slaughtering	J
Esd	Energy requirement for scalding & defeathering	J
Ee	Energy requirement for evisceration	J
Ewc	Energy requirement for washing & chilling	
Ep	Energy requirement for packaging	
ET	Total energy requirement for all cashew kernel/nut processing operations	J
t	Time taken for a particular operation (i.e. ts, tsd, te, twc, tp)	h
C	Heating value of fuel used for a particular operation (i.e. Cs, Csd, Ce, Cwc, Cp)	J/Kg or J/l
W	Quantity of fuel used for a particular operation (i.e. Ws, Wsd, We, Wwc, Wp)	l
P	Electrical power consumed for a particular operation (i.e. Ps, Psd, Pe, Pwc, Pp)	kW
N	Number of persons involved in a particular operation (i.e. Ns, Nsd, Ne, Nwc, Np)	
K	Efficiency of the electric motor used for a particular operation (i.e. Ks, Ksd, Ke, Kwc, Kp)	

Subscripts: s = slaughtering; sd = scalding & defeathering; e = evisceration; wc = washing & chilling; p = packaging