Energy Audit of a Wheat Processing Plant in Port Harcourt, Nigeria

Christian R. Green, John I. Sodiki, and Barinyima Nkoi

Abstract—In this study, energy audit of a wheat processing plant in Port Harcourt, Nigeria has been carried out. A walk-through energy audit method was undertaken to identify the major sources of energy in use, identify the losses in energy usage, identify areas to improve energy usage, determine the level of energy consumption of the various energy sources and recommending policy measures that will enhance energy savings in the plant. The analysis showed that eight defined unit operations were required for the production of wheat flour, namely Truck Loading, Intake and Storage, Cleaning, Tempering or Conditioning, Holding Bin, Milling, Finished Product and Packaging. The types of energy used were electrical, thermal (diesel and gas), and manual with proportions of 14.63%, 85.31% and 0.05%, respectively of total energy input. Average energy intensity was estimated to be 1.36GJ/tomme for the production of wheat flour for the 5 years (2011-2015) study period. The most energy intensive operation was identified as the milling process with percentage energy input of 44.39% (123837.60MJ) followed by Finished Product and packaging with percentage energy input of 36.17% (100885.92MJ). It was observed that the plant did not sufficiently utilize energy as the energy use ratio was below 1 due to some factors that contribute to energy wastage. The exergy analysis showed that the roller dryer accounted for the major loss in the process with an inefficiency of 44.8%. The useful work was 5.3kJ and exergy loss was 15.6kJ in the roller dryer. The study concluded that energy is not sufficiently utilized in the industry resulting in high pricing of wheat flour products.

Index Terms—Audit; Energy; Exergy; Efficiency; Wheat Flour.

I. INTRODUCTION

Energy is a fundamental aspect of our modern day economy and a vital input in almost all production process in any industry. The total energy consumption of the industrial sector of developed countries contributes to around 30 to 40 per cent of total energy demand [1]. The most important resource to both human beings and industrial activities is energy and energy consumption was projected to increase by 33 per cent from 2010 to 2030 in the world [2].

A company having a design capacity of 1580 tonne of wheat per day and a storage capacity of 48000 tonne but presently having an output of about 800 tonne of wheat per day surely depicts ineffective utilization of energy. Furthermore, the use of ineffective electric motors and generation of electricity more than needed in the plant necessitates the need to study the factors responsible for such energy inefficiencies.

The aim of this study is to identify the energy inefficiencies in unit operations of a wheat processing plant as a means of improving the efficiency of the plant. The objectives of this study are: to study the pattern of annual energy consumption and utilization in the wheat flour processing plant, to identify the source of energy waste in the plant, and to establish appropriate methodologies for effective energy savings in the industry.

While conducting a research on the energy consumption during food process operations, Singh [3] explained that wheat processing involves Cleaning, Tempering or Conditioning, Holding Bin, and Milling operations and requires high and regular energy supply of about 870.624MJ, 617.472MJ, 268.963MJ and 18295.718MJ respectively for an average plant of 1500 tonne capacity to function.

A study on the energy consumption pattern and management in a beverage plant in Nigeria showed that there was an increase in energy intensity with a simultaneous decrease in production [4]. Furthermore, a study on cashew nut processing mill in Ibadan, Nigeria concluded that the mill depended more on fuel energy than the other two sources of energy (electricity and manual) [5]. According to them, fuel energy varied from 14.9MJ to 63.62MJ per kg of processed cashew nut; while electricity consumption varied from 5.56MJ to 13.48MJ per kg of processed cashew nut and manual energy varied from 1.25MJ to 3.08MJ per kg of processed cashew nut. A research conducted by Tolga et al. [6] to examine the input energy requirements and to make an economic analysis for wheat production for various farm sizes. Their results revealed that wheat production consumes a total of 20,653.54MJ/ha-1 energy depending mainly on fossil fuels.

An energy analysis conducted on a milling plant concluded that the most energy intensive operation is the milling unit with energy intensity of about 0.073MJ/kg (72.20%) of the total energy consumption in that plant, followed by the packaging unit using 0.015MJ/kg (14.39%) of the total [7]. According to them, optimization of the milling process and efficient utilization of fuel, electricity, thermal and manual energies would reduce drastically economic lose and the cost of flour and reduce to the barest minimum, the average energy intensity of 0.01MJ/kg required for the production of wheat flour.

The primary objective of energy audit is to recommend appropriate policies for bringing down energy consumption per unit of operation output or to lower operating costs [8].

An exergy analysis on a sugar processing plant by Bayrak

Published on January 24, 2019.
Authors are with the Mechanical Engineering Department, Rivers State University, Nigeria.
(e-mail: greenerpascal@yahoo.com; jsodiki_partners@yahoo.com; nkoi.barinyima@ust.edu.ng)

DOI: http://dx.doi.org/10.24018/ejers.2019.4.1.1073
et al [9] concluded that the plant comprises of four stages: sherbet production, distillation, thickening and crystallization. The exergy losses occurred mostly during the sherbet production due to irreversibility as a result of finite temperature differences at the production stages. The energy audit process must be carried out accurately enough to identify and quantify energy cost savings that are likely to be realized through investment in energy saving measures. Energy audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where there is scope for improving efficient utilization of resources [10].

II. MATERIALS AND METHODS

A. Plant Description

Energy audit was conducted on a wheat processing plant; Crown Flour Mill Ltd located in Rivers State, Nigeria. The plant operates on a double shift of 8 hours in daytime and 10 hours of night shift per day. The sources of energy in the plant are electrical, thermal (diesel and gas) and manual. The primary source of electrical energy in the plant, due to inconsistency in power supply from the Power Holding Company of Nigeria (PHCN), is the tri-generation plant comprising of two stand-by generators of output capacity 3.8MW each and a gas-fueled steam boiler primarily used for heating purpose. Cooling is accomplished through an absorption chiller powered by the exhaust from the generating sets.

B. Process Description

The process flow chart of the production system is shown in Fig. 1. Wheat is received and weighed using weighing machine capable of weighing loaded trucks. It is then transferred to the storage facility where it would be stored using elevators and conveyors. The wheat is tested for protein and other characteristics and graded into various categories. This is followed by cleaning which is done by first passing the wheat over series of coarse sieves that remove unwanted materials such as chaffs and straws. Stone may be removed by passing the wheat over sieves that allows stones to fall out and be trapped. The wheat is then passed over a magnetic separator to remove any metallic particle present. It is then tempered or conditioned by adding a little quantity of water (usually between 4 to 6 per cent by weight of the quantity of wheat) depending on the initial moisture content of the wheat being milled in order to soften the outer layer of the wheat grain to ease milling. The wheat is then allowed into the conditioning bins between 10 and 24 hours. The bagging process includes operations such as loading, weighing and sowing.

C. Data Acquisition

The data required for this study was obtained from a walk – through energy audit method carried out in the plant for a period of 5 years (2011 -2015). The following operational data were collected for analysis.

i. Annual electrical, thermal (diesel and gas) and manual energies consumed.

ii. Annual production output of the plant.

iii. Number of workers in the production of wheat flour per annum.

iv. Motor ratings of machines powered by electricity in the production of wheat flour per annum.

D. Data Analysis Procedure

From the operation data collected, the following procedures were employed to get them properly analyzed.

i. The three energy sources: electrical, thermal (diesel and gas) and manual energies were identified.

ii. Annual consumption of the energy sources and their consumption for the eight unit operations were evaluated to understudy the pattern of energy consumption

iii. Percentage breakdown of the total energy consumption was evaluated to estimate the dominant energy source.

iv. The energy use ratio of the plant per annum was evaluated to establish if energy is effectively used.

v. Operational data for each unit of operation was determined to identify areas of wasted energy

vi. Tables and figures showing energy consumption for various energy sources were generated for the study period.

E. Energy Model Equations

Energy consumption in the processing plant will be analyzed using the following:

III. EVALUATION OF ELECTRICAL ENERGY

The electrical energy input $E_p$ in kWh was evaluated by multiplying the rated motor power by the operational time.
and the motor efficiency which is assumed to be 80% [11].

Mathematically:

\[ E_{p} = \eta pt \quad (1) \]

where: \( E_p \) is the electrical energy in kWh
\( P \) is the motor power in kW
\( t \) is the operational time in h
\( \eta \) is the motor efficiency (assumed to be 0.8)

IV. EVALUATION OF THERMAL (DIESEL AND GAS) ENERGY

The thermal energy input \( E_t \) was calculated as the quantity of fuel consumed \( W \) multiplied by the corresponding calorific value \( C_f \) (lower heating value) of fuel [11]-[13].

Mathematically:

\[ E_t = C_f W \quad (2) \]

where: \( E_t \) is thermal energy input (J)
\( C_f \) is caloric value of fuel (J/L)
\( W \) is quantity of fuel (kg)

V. EVALUATION OF MANUAL ENERGY

Manual energy input, \( E_m \), in kW was estimated based on the maximum continuous energy consumption rate and conversion efficiency. The physical power output of a normal human being in the tropical climate is approximately 0.75kW sustained for 8–10 hours’ workday on the average [14].

Mathematically:

\[ E_m = 0.75Nt \quad (3) \]

where: \( E_m \) is manual energy input for a male worker (kWh)
\( N \) is the number of persons involved in the operation and \( t \) is the useful time spent (h)

VI. TOTAL ENERGY INPUT

For each unit operation, the total energy input is given as:

\[ E_i = E_p + E_t + E_m \quad (4) \]

where: \( E_i \) is total energy input
\( E_p \) is electrical energy power input (kWh)
\( E_t \) is thermal energy input (J)
\( E_m \) is manual energy input (kWh)

VII. ENERGY CONSUMPTION

This is the total energy consumed by each motor and generator in the plant. It is calculated using the formula:

Energy Consumption = Units Wattage x Number of Hours Used.

\[ E_C = Pt \quad (5) \]

where: \( E_C \) is energy consumption (J)
\( P \) is the power ratings for each unit (kW)
\( t \) is the operational time (h)

VIII. TOTAL ENERGY CONTENT (ENERGY OUTPUT) OF FINISHED PRODUCT

This is the energy output in a finished product of wheat flour. This is calculated using the model equation:

\[ E_0 = M_{FP} \times E_{CP} \quad (6) \]

where: \( E_o \) is energy of finished product (J)
\( M_{FP} \) is energy content of a unit mass of product (J)
\( E_{CP} \) is the mass of finished product (kg)

IX. ENERGY OUTPUT

The amount of energy used or consumed in a process or system. This energy is calculated from the equation:

\[ E_O = E_C \times \eta \quad (7) \]

where: \( E_o \) is the output energy (J)
\( E_C \) is the energy consumption and
\( \eta \) is the energy efficiency

X. ENERGY USED RATIO

Energy used ratio will be evaluated as:

\[ E_R = \frac{E_O}{E_i} \quad (8) \]

where: \( E_R \) is energy used ratio
\( E_i \) is total energy input
\( E_O \) is total energy output

XI. ENERGY INTENSITY

It measures how a unit of energy benefits the economy. It is used to indicate how effective a certain economy is using their input energy.

This value is calculated using:

\[ E_I = \frac{E_i}{E_t} \quad (9) \]

where: \( E_I \) is energy intensity
\( E_i \) is the Total energy of a particular operation (MJ)
\( E_t \) is the energy of the entire operation (MJ)

XII. ENERGY PRODUCTIVITY

It is used to understudy the energy efficiency of an industry or an economy. This value is calculated using:

\[ E_{productivity} = \frac{\text{Total energy consumption (MJ)}}{\text{Total production(kg)}} \quad (10) \]
XIII. PERCENTAGE ENERGY CONSUMPTION

This is the energy consumption in percentage. It is calculated using:

\[
\text{Energy} = \frac{\text{Energy Type}}{\text{Total Energy}} \times 100\% \tag{11}
\]

A. Exergy Model Equations

Exergy is not subject to a conservation law, but is destroyed due to irreversibility during any of the thermal processes, including drying, heating, boiling, freezing etc. for food industry. It means that reducing the irreversibility in a production system will increase the exergy (i.e. availability) and hence the efficiency of the system [15].

**Exergy balance**

The exergy balance in the plant is analyzed using the model equation:

\[
\Delta e_{\text{loss}} = e_{\text{in}} - e_{\text{out}} \tag{12}
\]

where: \(\Delta e\) is change in exergy, “in” and “out” represent inlet and outlet exergies.

The exergy of a flow crossing the system boundaries of an open system can be written as [16]:

\[
E_x = m(u_1 - u_0) - T_0(s_1 - s_0) + p_0(v_1 - v_0) \tag{13}
\]

where: \(m\) is the mass, \(u\) is the specific internal energy (kJ/kg), \(T_0\) is temperature, \(s\) is the specific entropy (kJ/kg K), \(P\) is pressure of each process stream and \(v\) is specific volume. The subscript “0” and “1” represents the initial and final states respectively.

Also, the net exergy changes of the process stream in and out of each unit operation in wheat production system were evaluated using the predictive model proposed by [17]:

\[
e_2 - e_1 = W_{U\text{, out}} + e_{\text{dest}} \tag{14}
\]

where: \(e_{\text{dest}}\) is energy destroyed and \(W_{U\text{, out}}\) is the work potential

**Exergy Efficiency and the Work Potential of the System**

The exergy efficiency can be evaluated with the expression:

\[
\eta_{\text{ex}} = \frac{e_{\text{out}}}{e_{\text{in}}} = 1 - \frac{e_{\text{dest}}}{e_{\text{in}}} = \frac{W_u}{(e_2 - e_1)} \tag{16}
\]

It can also be calculated using:

\[
\eta_{\text{ex}} = 1 - I_{\text{eff}} \tag{17}
\]

where: \(I_{\text{eff}}\) is the inefficiency of the system and is defined as the ratio of the irreversibility in each unit operation to the irreversibility in the overall operations.

\[
I_{\text{eff}} = \frac{I_i}{\sum I_{\text{all}}} \tag{18}
\]

Maximum improvement in the exergy efficiency for a process or system is obviously achieved when the exergy destruction or irreversibility is minimized. The useful work input into the system can be expressed by [18].

\[
W_u = W_{U\text{, out}} - W_{\text{surr}} \tag{19}
\]

where: \(W_u\) is the useful work and \(W_{\text{surr}}\) is the work done by the surrounding.

XIV. RESULTS

A. Energy Consumption of the System

The study reveals the various unit operations carried out at the industry for wheat processing. These are shown in Fig. 1.

Table I shows the annual energy consumption and production output for the wheat flour processing industry. The highest energy consumption and production output recorded are 66,135GJ and 197,760 tonne respectively, in 2015, while the least energy consumption and production output recorded are 52,917GJ and 39,552 tonnes of wheat flour respectively, in 2011. The table also shows that an increase in production output results in an increase in total energy consumption. This is further shown in Fig. 3.
Table II shows that thermal (diesel and gas) energy was the highest consumed form of energy accounting for an average of 73% of the total energy input for the study period, followed by electrical energy accounting for an average of 25% of the total energy input, while manual energy expended in operating machines and lifting of loads was found to be the least, accounting for an average of 1.57%.

Table III shows the various unit operations in a wheat processing plant. From the table, it is shown that the Milling process accounted for the highest energy consumption of 44% of the total energy input, followed by Finished Product Storage accounting for 36% of total energy input. The least energy consumption process is the Truck Unloading process accounting for 0.01%. It also shows that thermal energy expended in the plant during production of wheat flour accounted for 85% of total energy, followed by electrical energy accounting for 15% and manual energy accounting for 0.05%. This is further shown in Fig. 4 and 5.

Table IV shows the annual energy productivity and energy use ratio of the plant for the 5-year study period. From the table, it is shown that energy used ratio is less than 1, indicating inefficient use of energy. However, energy productivity indicates that the industry is still making profit despite this inefficiency in energy usage.

B. Exergy Expenditure of the Plant

The exergy analysis of the system gave insight to the inefficiencies and the opportunities for exergy loss minimization of each of the unit operations involved in the production of wheat flour. Conceptually, the exergy calculations of the system were divided into process stream...
exergy and utility exergy. The high destruction of exergy implies that the system has lost some of its ability to produce work.

<table>
<thead>
<tr>
<th>Unit Operation</th>
<th>Exergy Change (KJ)</th>
<th>Useful Work (KJ)</th>
<th>Inefficiency in unit operation (%)</th>
<th>Efficiency in Unit Operation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller dryer (Steam)</td>
<td>9.6</td>
<td>5.3</td>
<td>44.8</td>
<td>55.2</td>
</tr>
</tbody>
</table>

Table V shows the exergy balance in wheat flour production. The exergy analysis showed that the roller dryer accounts for the major loss in the process with an inefficiency of 44.8%. The useful work was 5.3kJ; exergy loss expended is 15.68kJ in the roller dryer.

XV. CONCLUSION

The energy audit of a wheat flour processing plant in has been carried out. The study reveals that the energy sources in use are electrical, thermal (diesel and gas) and manual energies accounting for 25.42%, 73.01%, and 1.57% of total annual energy consumption, respectively, indicating that the industry uses mainly generating set for electrical power generation during production. This must be due to the epileptic nature of power supply from the National Grid. This study also reveals that eight unit operations are involved in wheat flour processing, namely Truck Unloading, Intake or Storage, Cleaning, Tempering or Conditioning, Holding Bin, Milling, Finished Product Storage and Packaging, with energy consumption of 21.6MJ (0.01%), 14067.84MJ (5.04%), 8113.92MJ (2.91%), 16227.84MJ (5.82%), 7033.92MJ (2.52%), 123837.60MJ (44.39%), 100885.92MJ (36.17%), and 8769.6MJ (3.14%), respectively. The milling process accounted for the highest energy consumption (44.39%) of the total energy input, followed by the finished product storage process accounting for 36.17% of the total energy input. The exergy analysis performed on unit operations indicated that the roller dryer is the main source of energy waste, accounting for 44.8% inefficiency.

To curtail the unnecessary energy waste and reduce the cost of energy consumption in the wheat processing plant, the following are recommended:

I. Perform proper maintenance and control so as to improve energy productivity in the plant.

II. Avenue for minimizing energy loses in the roller dryer should be investigated.

ACKNOWLEDGMENT

The authors wish to express their profound gratitude and appreciation to Crown Flour Mill Ltd for providing the log sheets and other relevant materials from which the data for this study were obtained.

REFERENCES


