Energy Audit of a Crumb Rubber Manufacturing Industry

(Case Study of Imoniyame Crumb Rubber Processing Factory Ughelli)

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Abstract- Crumb rubber production is an energy intense process that requires proper monitoring to avoid energy waste. Owing to the high cost of energy and its impact on production cost, an energy audit of Imoniyame Holdings Limited is necessary for production cost reduction and to remain relevant in a competitive environment. A one year energy audit of the plant was carried out. Detailed performance data were collected for the major energy consuming sections of the plant. These were the oven, production lines and the lighting sections. From the work, the energy consumed by the oven for the period of audit was 9,472.32GJ which was 53.6% of the total energy of 17,614.343GJ consumed for the period. The oven is therefore recognized as having the highest energy saving potentials. The specific energy consumption and the specific energy cost of the plant were 4.298MJ/kg and N13.87/kg of crumb rubber respectively. The heat losses through the stack can be recovered by the introduction of a heat exchanger between the stack and the circulating water. It was shown that when this is done, an annual savings of N3,204,929.56 will be made from the cost of diesel fuel. It was also ascertained that the specific energy consumption and the specific energy cost will be reduced to 3.99mJ/kg and N13.09/kg of crumb rubber respectively.

Index Terms- Energy audit; manufacturing processes; specific energy cost/consumption; energy saving potential; heating processes.

I. Introduction

Background of the study

The alarming high cost of energy has necessitated the need for a proper check of its usage. Although energy losses in plants or industrial processes are inevitable, there is need to reduce such losses. The inspection, survey and analysis of energy flow is significant in the conservation of energy in any industry. It has a direct effect on the overall cost of the product. This is a major aspect of interest to the management of a production plant. In addition to saving cost and remaining competitive, energy efficiency or conservation is also an essential step being currently taken towards overcoming the mounting problems of worldwide environmental pollution and global warming caused through the release of harmful emissions and green house gases into the atmosphere from industrial activities.

Demonstrating good environmental image will not only be required but will have a beneficial effect on a company's reputation, Lovetta (2002). All energy sources need to be used in ways that respect the atmosphere, human health and the environment as a whole. This is important because scientific data and a range of disastrous consequences such as change in rainfall patterns, melting of polar ice-caps, causing flooding and harming air quality. A number of studies on energy and environment have concluded that environmental degradation can be reduced by switching to cleaner fuels and reducing the energy intensity of economic activity by using best practices and best technology in both energy production and consumption, Utomo (2008).

Imoniyame Holdings Limited was founded in 1998 to produce crumb rubber (processed rubber), which is a major input in tyre manufacturing. The firm gets raw rubber lumps from plantation of small-holder farmers and processes them into crumb rubber for exports. Findings showed that the firm is exporting nearly 100% of its products to Bridgestone Tyre Company, one of the largest tyre companies in the world. Findings also revealed that in 2012, the firm spent about N80 million on energy. This huge amount, calls for proper energy investigation.

1.2 Importance of energy audit to production plant

According to Ughwumiakpor (2002), energy audit is important for the proper planning, operation and maintenance of production plants and processes. Managers need the result of such audit to take decision on which process out of competing numbers that should be selected for use, bearing in mind the efficiency of energy utilization, environmental implications and process cost effectiveness.

Few factories have a precise idea of the energy consumption of different production areas and in the absence of a detail internal monitoring; the energy efficiencies of the different process operations are unknown. Knowledge of the energy consumption in the different areas of a factory is very important for several reasons and these are as follows:

(A) The cost of fuel has risen remarkably in recent years. Energy saving measures has therefore become inevitable. Apart from the more obvious improvements in the housekeeping aspects of factory practice, most effective savings are usually made in the high energy consuming area. This area can be highlighted by energy audit.
(B) If a new or modified production line is being proposed, the cost of energy required to run it is usually compared with cost of energy required to run the existing processes. It is only by having a detailed breakdown of fuel consumption in the different areas of a factory can such a comparison be made and this is provided by energy audit.
(C) If an operator wishes to compare his energy efficiency with that of a competitor in the same industrial sector, only by identifying the energy requirements of different operational areas of the factory can a satisfactory comparison be achieved. Without a detailed audit, it is not possible to achieve this.
(D) Energy audit gives industry-based management operation engineers and accountants a sound method of adopting fuel cost between different cost-centres.
(E) Factories take interest in energy audit in order to have an overview of the environmental impact, of their operations. It is essential to carry out a wide-ranging examination of the neighborhood and in some cases on the nation. Such audit is called environmental impact audit.

The energy consumer be it in industry or domestic sector has a responsibility of improving the way in which the energy is used. Energy audit will highlight the most energy-intensive items, or equipment of a plant or process. If correctly carried out, it should enable the energy manager to identify any inefficiency or wastage area that needs rectification. Significant savings will probably be made with comparatively low-capital investment, but on the long term the effectiveness of planning and forecasting of energy demand and prices will determine where future investment in new plants or modifications to existing equipment will be directed.

1.3 **Statement of the problem**

In view of the fact that environmental degradation and its negative effect on human health and the environment is a consequence of industrial waste and that the cost of the crumb rubber production is on the increase as a result of the high cost of energy, a stack heat recovering system which will reduce energy consumption and at same time reduce environmental pollution will be introduced.

1.4 **Aim of the study**

The aim of this study is to identify and evaluate opportunities that will reduce production cost through energy conservation and planning in a rubber crumb processing factory.

1.5 **Objectives of the study**

The objectives of the study are:

i. To determine types and sources of energy used.
ii. To identify areas of high-energy consumption by carefully examining the records of the energy consumption.
iii. To ascertain the specific energy cost and the specific energy consumption.
iv. To determine the efficiencies of major energy consumers like burners and to determine where the most significant energy saving potentials are.
v. To determine the amount of energy saved and the cost equivalent.
vi. To develop technical solution to reducing the energy losses identified.
vii. To carry out economic analysis of the selected solution.

1.6 **Methodology of the study**

The following methodology was adopted

i. Study of similar works done on crumb rubber either through available text, library and/or internet.
ii. A visit to the company (Imoniyame Holdings Limited Ughelli) to gather existing data of all energy systems and facilities.
iii. Discussion sessions were held with head and staff of various departments of the company in order to obtain relevant information concerning their operations and facilities.
iv. From the data collected, analysis was made to determine where the most significant energy saving potential could be found.
v. The major energy consuming systems were analyzed based on the first law of thermodynamics since this will account for all energy and materials input in terms of demand, utilization and losses.

1.7 **Limitation of the study**

Various limitations faced by researchers have direct effect on the actualization of the real goal of the research. One of the major limitations in the course of this study is the poor record keeping of the establishment. The period of one year audit could also be seen as insufficient for an elaborate energy audit report. However, the records were just for a period of one year.

Notwithstanding the limitation, the audit procedure developed could stand as standard of comparison for further energy performance evaluation of Imoniyame Holdings Limited Ughelli. It should be noted that the limitation identified above do not in any way invalidate the study. It is only fair to state that one was aware of the limitations.

II. LITERATURE REVIEW

2.1 Levels of energy audit

An energy audit is a systematic approach to problem solving and decision making. The primary goals of an energy audit are to qualify and quantify how the plant energy systems are performing. Energy audits vary in depths depending on the plant energy distribution system, the scope and capabilities offered by the energy auditor. There are three progressive levels or types of audit.

1. **Walk –Through Analysis/Preliminary Audit**

This is also called simple audit. It involves brief interviews with site operating personnel, a review of the facility's utility bills and other operating data. It is geared toward the identification of the potential for energy improvements, understanding the general plant configuration and defining the type and nature of energy systems. Usually, the walk-through audit report does not provide detailed recommendations, except for very visible projects or operational faults.

2. **Energy Survey and Analysis**

The energy survey and analysis starts with the findings from the walk-through analysis. It is done by evaluating the plant energy system in detail to define a variety of potential energy efficiency improvements. This study involves a detailed analysis of energy consumption to quantify base load, seasonal variation and effective costs.

3. **Detailed Analysis of Plant**

This is called the investment grade. Before making this level of investment, the plant management will want to have much more thorough and detailed understanding of the benefits, cost and performance expectations. A detailed audit will provide technical solution options and economic analysis for the factory management to decide project implementation or priority.

2.2 Energy audit in the production industry

Industrialization entails the manufacture of a great number of products in large quantities.

Invariably, energy is required among other inputs in the primary and auxiliary processes. Therefore energy audit of production plants entails a comprehensive examination of energy available, sources, inputs, usage and possible ways of converting wastage into useful forms with the overriding aim of reducing the production cost of a commodity from the plant. The renewed interest in energy audit gained its momentum as a result of economic, environmental and political changes in the last three decades. Before this time, low prices of available fuel and poor awareness of the limited qualities of fuel resources had created a lapse in the necessity for organized energy studies.

The industrialized world, notably United Kingdom and United States, picked overwhelming interest in energy audit and management, including conservation. After the 1973/74 fuel crises, when the United States of America had a fuel embargo, even though it lasted for one year, it made the Americans to start looking inward on the agreeable terms for conservation and audit that was to protect her from subsequent short-fall in fuel supply. Since then, several countries like Nigeria have seen the gains that could be realized from such a practice.

Some energy audits done earlier on production plants were done by simply cost-evaluating the plant material flows or by the use of "crude" arithmetic procedures which do not give insight to the efficiency of the system operations or ways of improving them largely because they were carried out by analysts who were not devoted to the engineering concerns. A good example is the resource cost audit which expresses everything in monetary terms. Its limitation is that energy and materials cost world-wide is not uniform. Also, it cannot explain the extent to which machines and operations are efficient.

A detailed overview of an industrial energy audit approach is shown in Fig. 2.1 by Ali, (2010). In this lay-out, a step by step approach on how to carry out energy audit is shown.

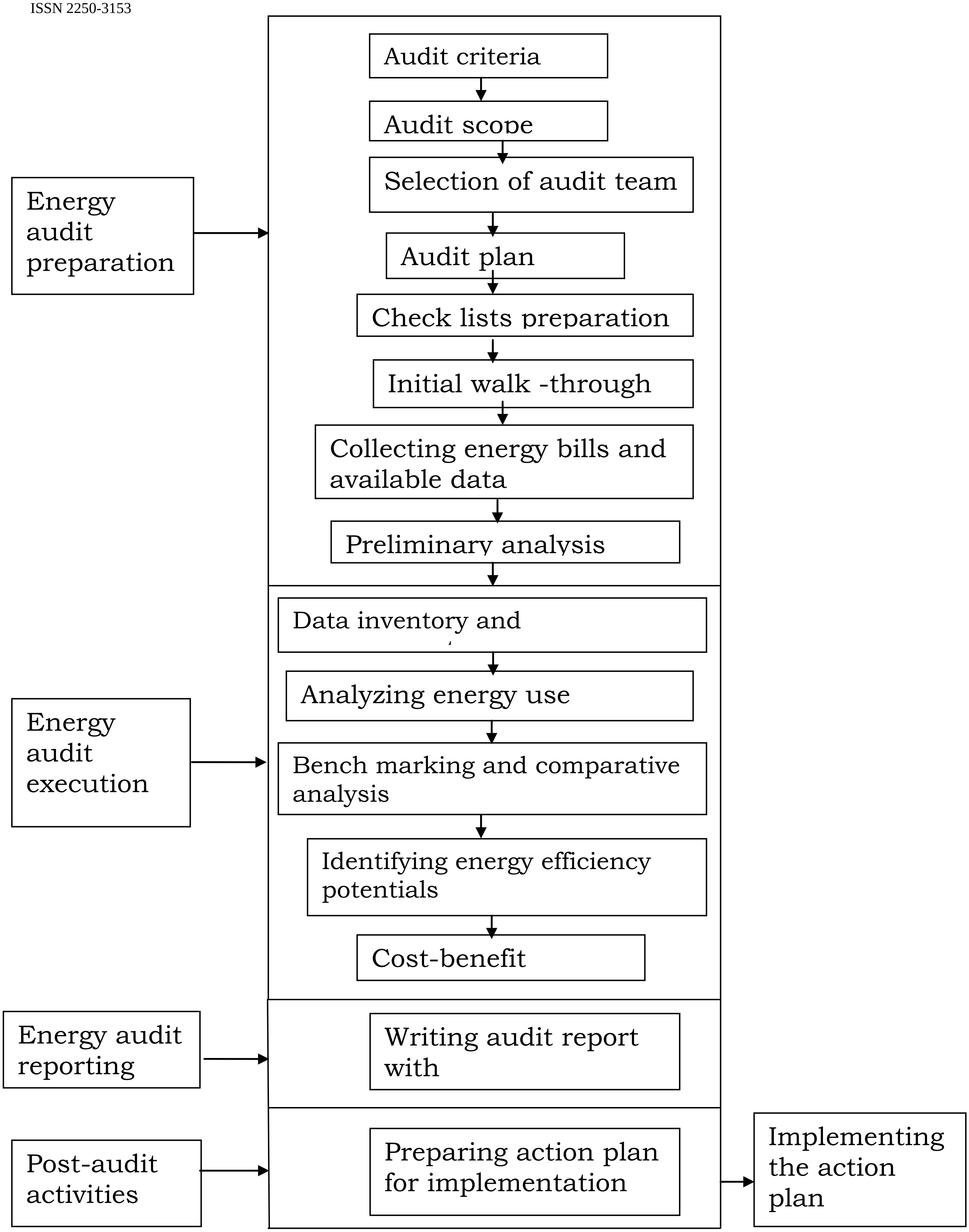

Fig. 2.1 Overview of an industrial energy audit

According to Aiyedun and Ologunye (2001), in an energy audit work in the food industry, with Cadbury Nigeria PLC as case study, it was noted that for many industries, the cost of energy consumed is a major factor in the operation cost and must be closely monitored and reduced to a possible minimum in order to improve profitability and competitiveness. In their work, data was collected for a five-year period (1994-1998) and various energy performance parameters were used in analyzing the data. Data collected included annual electricity bills, fuel oil and water consumption and annual production over the period of 5 years.

The intensity of energy was defined as the ratio of the energy consumed per year in GJ to the floor area of the factory in square meters. The treated floor area of Cadbury Nigeria PLC was estimated to be 22,294.55m^2. The normalized performance indicator (NPI) was defined as:

$$NPI = \frac{\text{Total energy consumed}}{\text{Floor Area}} \times \text{hours of use factor}. \qquad \text{……………..} (2.1)$$

The normalized performance indicator is a parameter used in assessing the energy performance of a factory. The value of NPI obtained for a factory is usually compared with standard NPI values quoted by the energy efficiency office (EEO) for such a factory. The NPI value calculated for the five-year period gave an average of 1.16GJ/m^2. This was rated as “fair” for the factory, meaning that significant savings and improvement in energy usage is still achievable. The average cost of energy input per kg of product was estimated as N4.96/kg. The highest value of N6.09/kg in 1995 was attributed to the wastages and lack of cost consciousness.

According to Agbro (2007), in an energy audit of a glass factory (Beta Glass PLC-Delta Plant), it was established that to produce one ton of glass in the plant, about 10.89GJ of energy is required at a cost of N5,343. It was revealed in the work that some glass plants around the world use as low as 7.5GJ of energy to produce a ton of glass. It was noted that about 52.55% of the total energy input to the plant and about 84.52% of the total energy input to the manufacturing process was consumed in the furnace. The work showed that the furnace was the most energy intensive unit in the plant and also holds the greatest energy saving potential in the plant. The unit energy consumption of the furnace was estimated at 5.78GJ per ton of glass. This according to the work competes favourably with what is obtainable in some present day furnaces.

In another energy audit work carried out by Clarke and Wilson (1993), study was made on the energy required to produce a wide range of major industrial goods. In their work, result of two energy audits in the engineering sector, food can manufacture and construction machinery (an earth moving grader) were highlighted. For food cans, the study shows a process well optimized in terms of energy consumption with little prospect of significant future reduction in the energy required for their production. For the grader, improvements were shown to be possible both from modification to the process which would directly reduce the energy needed, and at the design stage where the materials needed in the finished products are determined.

In the audit study, the energy used directly and indirectly in each step of the manufacture was considered. The direct energy used is the fuel and electricity attributable to the production of the product. The indirect energy use include the energy which has to be used to provide the materials used as well as the other goods and services needed for the manufacture of the product. The overall energy requirement for making a product is the gross energy requirement (GER) while the energy used within the factory walls is the process energy requirement (PER). These are expressed as energy requirements per unit of product and are often expressed in terms of Giga Joules per tonne of product.

2.3 **Energy audit methods**

Basically, the two scientific approaches to energy audit of production plants are the first and second laws of thermodynamic method of audit and each of them gives efficiency of plant operation by quantifying the energy together with it’s utilization factor at every point in the flow process. These methods are followed because of their detailed and informative scientific backgrounds.

2.3.1 **Material-energy balance method.**

This method is also called input and output method of audit, and is based on the first law of thermodynamics and its corollaries. The first law is a law of conservation of energy and mass and states that neither energy nor mass can be destroyed, but that it could be changed from one form to another. For example chemical energy in fuel can be changed to mechanical, electrical, heat and light while mass can be changed from solid to liquid to gas.

The first law method of audit monitors in details material and energy flows right from the initial raw material and energy input to the final product. Arbitrary boundaries are set up between the plant and the surroundings to obtain thermodynamic state of the system under consideration. The whole plant is apportioned into units and the units are similarly divided into simple operation units to facilitate a thorough audit. From the analysis, the efficiencies of major process operations are calculated. The direction and modes of heat gains and losses from the units are calculated so that optimal consequences of the application of heat conserving measures may be derived. Thus the method provides a comprehensive audit of energy input, utilization and output.

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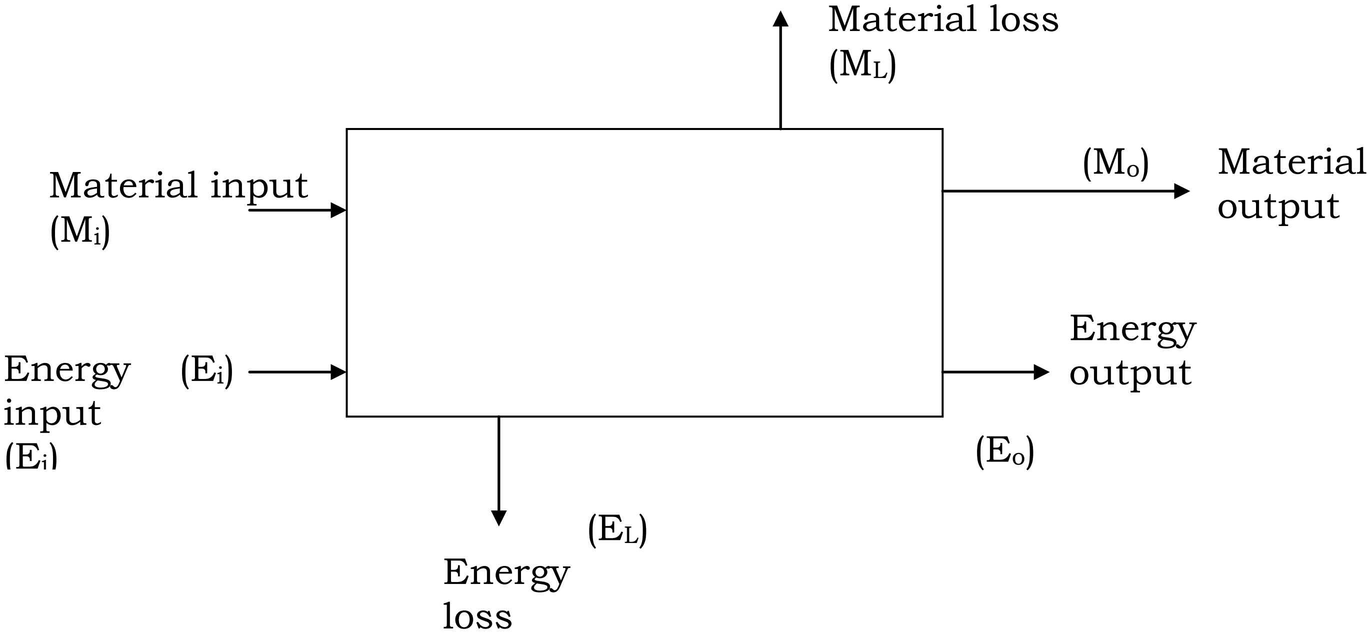

Fig. 2.2 A simple industrial mass-energy flow process

2.3.2 Available work (exergy) method

Availability of energy or exergy is a measure of the maximum reversible work transfer that can be realized when taking a fluid at any state P_1 and T_I from its given state to a "ground" or "dead" state which is at the lowest energy potential, and in which it is in thermal and mechanical equilibrium with the environment. The ground state may be defined by:

$P = P_0$, $T = T_0$, $Z = Z_0$ and ~~u~~ = o.

The above definition is based on the second law of thermodynamics. Energy audit analysis carried out based on the second law, calculates the grade of energy required at each process in terms of available energy. It usually encompasses heat and material balance for the process but extends to include entropy changes and the attendant losses to available energy.

For a non flow process, availability or exergy:
$= (U-U_o) + P_o (V-V_o) - T_o (S-S_o)$ - - - - - 2.3
$= (U + P_oV - T_oS) - (U_o + P_oV_o - T_oS_o) = A - A_o$ - - - 2.4
The property $A = U + P_oV - T_oS$ is called the non-flow exergy function.

For a steady flow process,
Availability or exergy $= (H - T_oS) - (H_o - T_oS_o) = B - B_o$ - (2.5)
The property B = H – ToS is called the steady flow exergy function. In the above equation,
$U - U_o$ = change in internal energy
$S - S_o$ = change in entropy
$V - V_o$ = change in volume
$H - H_o$ = change in enthalpy.

2.3.3 Adoption of the method of audit

The material – energy balance method serves as a spring board for the available work method. The material –energy balance method gives the amount of material and energy at a specific plant unit while the available work method gives the effectiveness of the various processes in the units. It is thus clear that the two methods compliment each other. A combination of the two methods facilitates realistic and practical results. Owing to the challenges of obtaining all the input data required for the application of the second law method of audit and the fact that there has not been any major energy audit project on the plant under study, this audit will be based on the first law of thermodynamics, that is the material – energy balance method. However, the availability method will also be incorporated where it is found necessary.

2.4 Crumb rubber production in nigeria

According to National Rubber Association of Nigeria (2002), rubber production has been on the downward trend in recent times, falling from 113, 479 tpa (tons per annum) before the advent of crude oil to 46,000 tpa in 2004. The industry witnessed exit of major players between 2000 and 2001, when international rubber prices crashed to as low as $50 per ton. Reasons for consistent lower production in the industry ranged from low yield in plantations, dwindling international rubber prices to volatility of oil prices and energy challenges. Shortages in supply of rubber from rubber trees further increases the pressure on the industry. Raw materials, which are the lumps from rubber trees are in short supply because most of the trees were planted in the 1960s and they have a life cycle of about 30years.

2.5 Crumb rubber production process

There are four production lines in Imoniyame Holdings Limited Ughelli (IHL). The four production lines are independent of each other but operate basically with the same principle. Each of the lines is divided into two sections, wet end and dry end. The natural rubber latex tapped from rubber plantations are processed from the wet end to the dry end with the aid of electric motor driven conveyor belts and chains.

2.5.1 Wet end procedure

The scaled and bought rubbers from customers are conveyed into a soaking pool by belt. This helps to remove initial dirt like sand attached to the rubber. There is a stirrer in the pool ensuring that dirt is partially separated from the rubber. Processes under the wet end are as follows:

(A) **Slab cutting machine**

The rubbers from the soaking pool are transferred into slab cutting machine with the aid of a conveyor belt. The machine cuts the rubber in pieces before they are transferred into a braker. The pieces of rubber are transferred into a pre-cleaning pool. Thereafter, the stirred pieces of rubber are transferred to a braker for further reduction of size.

(B) **Hammer mill**

The hammer mill is separated from each other by a pre cleaning pool and a conveyor belt. The hammer will reduce the rubber latex further to ensure dirts are not trapped in between latex. After a thorough hammering, the rubber latex is conveyed to the creeper with a chain bucket.

(C) **Creeping machine**

Like the hammer mill, the creeping machines are ten in number. They are usually referred to as CP1 to CP10. There is a shredder between CP4 and CP5 and a bank pool (BP1) between CP8 and CP9. There is also a bank pool (BP2) between CP10 and the second shredder. This arrangement is necessary for a perfect and a dirt-free crumb rubber production.

(D) **Shredding mill**

After the creeping process that takes place from CP1 to CP4, the rubber latex is passed through a shredder mill. There are two shredder mills, namely SM1 and SM2. The shredder reduces the rubber to a finer particle. This is usually the last stage of dirt screening. SM1 reduces the rubber latex to a fine particle that will be creeped in CP5 to CP8 before they will be stored in the first bank pool (BP1). After much stirring, the materials are then conveyed to CP9 and CP10 for further creep actions. From CP10, the materials are conveyed to the second bank pool (BP2). The materials are passed to SM2 for the final shredding process. This marks the end of the wet end process.

2.5.2 Dry end procedure.

The materials from the wet end are transferred to the suction pump which is the first stage of the dry end procedure. It is then transferred to the drying section through a trolley system. Some of the dry end procedures are:

(A) **Burner chambers.**

The burners G2 and G4, usually attached to the oven are arranged in series. The materials are passed to the oven whose temperature is regulated to 115^0C and stay there for about 15 minutes. The dried, hot materials are then transferred to a cooling section. The cooling fan blows off the heat contained in the materials. A huge amount of heat energy is released to the atmosphere through the stack each time the oven is open for the trolley to feed in materials.

(B) **Finishing section**

The compressed material is then passed through a metal detector machine (MDM). 36 baled bags of 35kg each make up a crate or pallet. A sample of the finished products is taken to the laboratory for testing to ensure that world and demand standard of Standard Indonesia Rubber (SIR) is met before packaging for shipment. The entire production process is summarized in a schematic diagram shown in Fig. 2.3

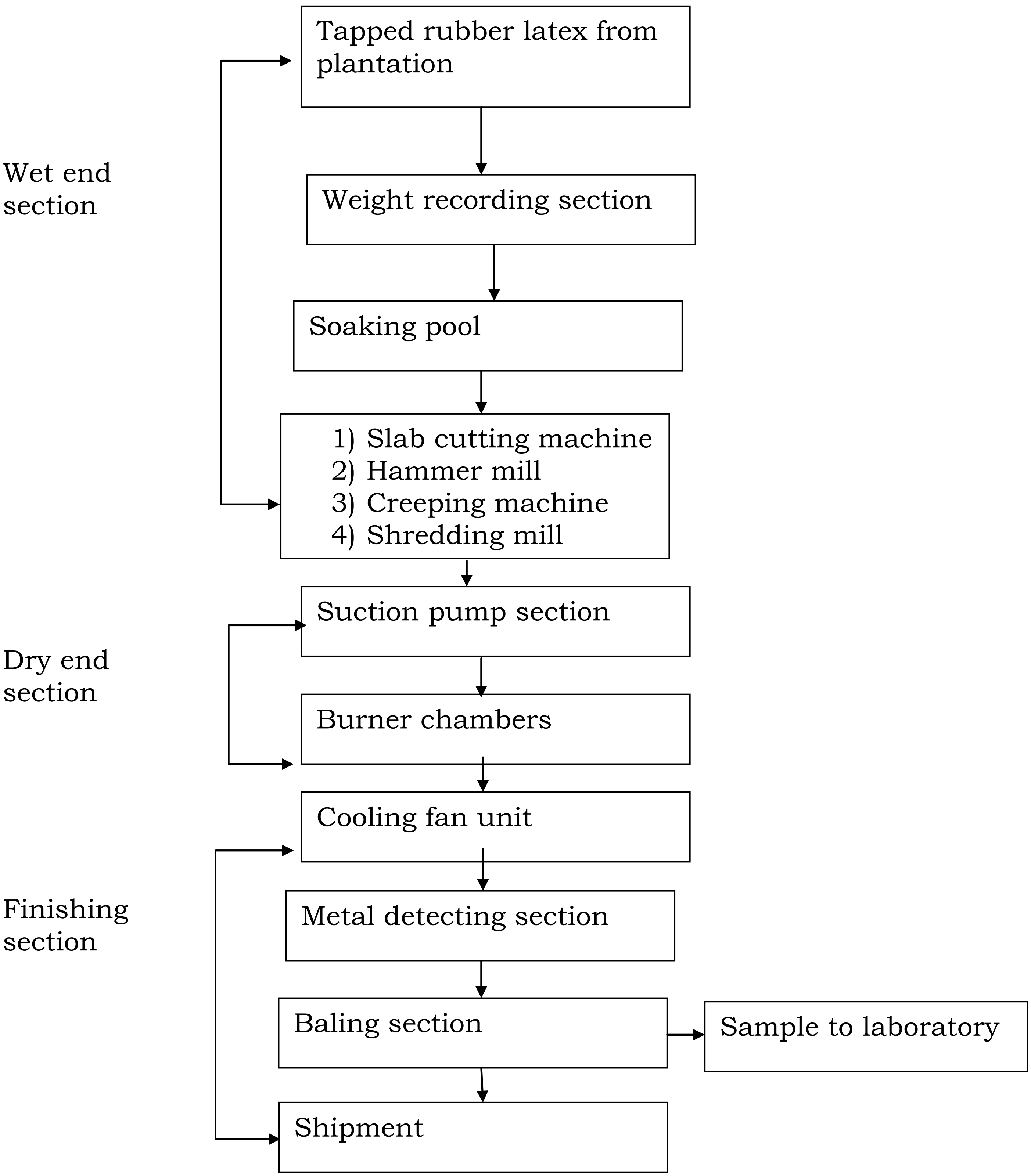

Fig 2.3 Schematics of crumb rubber production process

2.6 Laboratory test of crumb rubber

Before a produced crumb rubber is packaged for delivery, various tests are carried out to ensure quality control quality assurance, customers' requirement and world rubber standards are met. The main tests are as follows:

(A) Determination of ash content:

Ash from the oxidation of natural rubber represents a minimal figure for the amount of mineral matter comprising potassium, magnesium, calcium and sodium and the trace elements in the rubber. To determine the ash content of a lot Specified Singapore Rubber (SSR), a test portion of 5-10g is cut from the homogenized piece and weighed to the nearest 0.1mg. It is placed in a crucible which has previously been weighed and then put in a muffle furnace of temperature 550 ± 20^0C and the door closed. When ashing is complete, the crucible is cooled in desiccators and weighed to the nearest 0.1mg to conform to the grade for which the rubber has been tested.

(B) Determination of volatile matter:

Volatile matter in natural rubber consists primarily of moisture but includes any other materials volatile to 100^0C. Excessive moisture results in mould growth and malodour during storage and shipment. To determine volatile matter, a test portion of approximately 10g is weighed to the nearest 1mg. It is sheeted out to 2mm and then dried at 100 ± 30^0C for four hours until the loss in weight on successive weighings after heating periods of 30 minutes is less than 1mg.

(C) Determination of nitrogen

Nitrogen occurs in natural rubber usually as a protein and the determination is therefore to provide an estimate of the protein content in the lot of SSR being tested. The process used is a semi-micro procedure where in the rubber is oxidized by heating a mixture of potassium sulphate and converting sulphuric acid, together with a catalyst, thereby converting nitrogen compounds into ammonia hydrogen sulphate, from which the ammonia is removed by distillation after making the solution alkaline. The liberated ammonia is absorbed in boric acid solution and titrated with standard acid.

(D) Determination of plasticity retention index

The plasticity retention index (PRI) is a measure of resistance of raw material rubber to oxidation. A high resistance to oxidation is shown as a high value of the index. The test includes measurement of the rapid plasticity of the rubber test pieces before and after heating in an oven. The rapid plasticity is measure in the Wallace rapid plastimeter and heating is carried out on punched test pellets for 30 mins at 1400^0C. Laboratory technicians measure the rapid plasticity of heated pellets on the Wallace rapid plastimeter.

(E) Determination of dirt content

One of the major criteria of SSR is the dirt content of any lot. To determine this, a homogenized test portion of 10-20g is cut into 1g pieces and dissolved in xylene or white spirit to which is added a peptizing agent. When the rubber is completely dissolved, the solution is poured through a sieve and the trapped dirt weighed. The dirt content is expressed as a percentage of the test piece.

III. METHODOLOGY

3.1 Sources of energy

The energy consumed in the plant, comes from two main sources: The Diesel fuel and Benin Electricity Distribution Company (BEDC). The diesel fuel is used for the running of two standby diesel generators (Cater-Pillar, 3512 generator set) and two burners Grade 2 (2G) and Grade 4 (4G) attached to the oven. When there is BEDC supply, the plant runs wholly on it except for the burners that uses diesel always.

3.2 Procedure for energy data collection

The monthly electrical energy consumption is measured in kWh in a central meter. The rating in cost per kWh for each month was also taken from the meter. Since there were no sub meters, the central meter billing was used for the entire plant. Also stated in the bill are the fixed charge and the value added tax (VAT). The collection of the readings was achieved using the following equations.

$$\text{Cost} = \text{Reading (kWh)} \times \text{cost per kWh} \qquad (3.1)$$

$$\text{VAT} = 5\% \,(\text{cost} + \text{fixed charge}) \qquad (3.2)$$

$$\text{Total monthly cost} = \text{cost} + \text{fixed charge} + \text{VAT} \qquad (3.3)$$

Diesel consumed was read from stored tank record. The tank is calibrated in cm. 1cm equivalent is 112 litres. The cost per litre for the period of audit is N105.00. Since there were no sub-meters indicating quantity of diesel consumed by each burner and the generator, the records were then taken from the stored tank.

Mass of diesel (kg) = Volume (litres) x specific gravity of fuel…………………………….3.4

3.3 Crumb rubber production

The monthly production records were collected from the production section. The monthly production are shown in Table 3.1

Table 3.1: Monthly production output

Month (2014)	Production output (Metrictonne)
Jan-14	839.825
Feb-14	719.075
Mar-14	733.145
Apr-14	350.665
May-14	304.255
Jun-14	81.235
Jul-14	202.044
Aug-14	183.680
Sept-14	145.880
Oct-14	159.005
Nov-14	166.565
Dec-14	219.100
Total	4,104.474

3.4 Production period

From the information gathered from the records keeping sections, it was clear that operation/production were not done on Sundays. This audit will therefore be based on an average of 26days in a month. The numbers of working days for the period of audit are shown in Table 3.2.

Table 3.2: Number of days in each month of 2014

Month (2014)	No of Sundays	Other days
JAN-14	4	27
FEB-14	4	24
MAR-14	5	26
APR-14	4	26
MAY-14	4	27
JUN-14	5	25
JUL-14	4	27
AUG-14	5	26
SEPT-14	4	26
OCT-14	4	27
NOV-14	5	25
DEC-14	4	27
	52	313

$$\frac{313}{12} = 26.083333 \approx 26$$

3.5 Oven energy efficiency evaluation

The basic idea is that, if an oven is operating steadily, the mass flowing out of the oven is equal to the mass flowing into the oven. Similarly, the energy in is equal to the energy flowing out. These balances are dependent on the assumption of steady operation, so that the accumulation of mass and energy inside the oven can be neglected. It is understood however, that an operating industrial oven/furnace does not operate under perfectly steady conditions. In an energy assessment, the steady-state idealization is more accurate when applied to a long-term average of oven operation, rather than to the instantaneous operation.

From the operating records, 420kg of crumb rubber are passed through the oven in 15mins. The inlet temperature of the crumb rubber into the oven is ambient temperature averaged at 27^0C. Also, the temperature of the burner is regulated to 115^0C.

$Q_{CR} = M_{CR} \times Cp_{CR} \times (t_2 - t_1)$ - - - - - - -(3.5)

Where:
Q_{CR}= Quantity of heat received by crumb rubber.
M_{CR}= Mass flow rate of crumb rubber,
Cp_{CR}= Specific heat capacity of natural rubber latex.
t_1 = Crumb rubber inlet temperature.
t_2= Oven/crumb rubber outlet temperature.
M_{CR} = 420 kg/15 mins = 0.4667 kg/s.
Cp_{CR}= 1880 J/kg ^{0}C = specific heat capacity of natural rubber
$Q_{CR} = 0.4667 \times 1880 \times (115\text{-}27)$
Q_{CR} = 77,210.848 J/s
Heat content or heat received by crumb rubber is 77,210.848J/s.

Also, heat supplied by oven = $M_f \times$ GCV, where M_f = mass of fuel, GCV = Gross calorific value of fuel. From Table 3.9, the burner's consumption rating is 11kg/h.

$$\text{Oven Efficiency} = \frac{\text{Heat received by crumb rubber}}{\text{Heat Supplied by oven}} \quad - \quad - \quad 3.6$$

$$= \frac{M_{CR} Cp_{CR} (t_2 - t_1)}{M_f \times GCV}$$

$$= \frac{77210.848}{11/3600 \times 46 \times 10^6}$$

= 0.54.93
Oven Efficiency = 54.93%

From the oven efficiency result evaluated, the amount of useful energy by the oven is 54.93% of the total energy supplied to the oven (i.e, 9, 472.32 GJ).

$$\text{Useful energy by oven} = \frac{54.93}{100} \times 9{,}472.32$$

= 5,203.145GJ

$$\text{Lost energy by oven} = \frac{45.07}{100} \times \frac{9{,}472.32}{1}$$

= 4, 269. 175GJ
These losses may be attributed to wall losses, opening losses, stack heat losses etc.

3.5.1 **Wall Losses (Q_{wa})**

An infra-red thermometer was used to measure the outer surface temperature of the various sections of the oven in order to calculate the heat losses through these sections. The temperature measurements were taken at about five points in each location and the average was computed.

The quantity of heat, Q released from the wall of a heating oven/furnace can be calculated using the formulae, Trinks and Mawhinnet (1967).

$$Q = ax\,(t_1 - t_2)^{5/4} + 4.88\,E\left[\left(\frac{t_1 + 273}{100}\right)^4 - \left(\frac{t_2 + 273}{100}\right)^4\right] \quad \ldots\ldots\ldots\ldots\ldots..3.7$$

Where:
Q = Quantity of heat released (kcal/m^{2}h)
a = factor regarding direction of the surface of natural convection.

For top (crown), a = 2.8, side wall, a = 2.8. For bottom (hearth), a = 1.5.
t_1 = Temperature of external wall surface of oven [^{0}C].
t_2 = Temperature of air around the oven [^{0}C].
E = Emissivity of external wall surface of oven.
Fig 3.1 Shows the size of the oven under investigation.

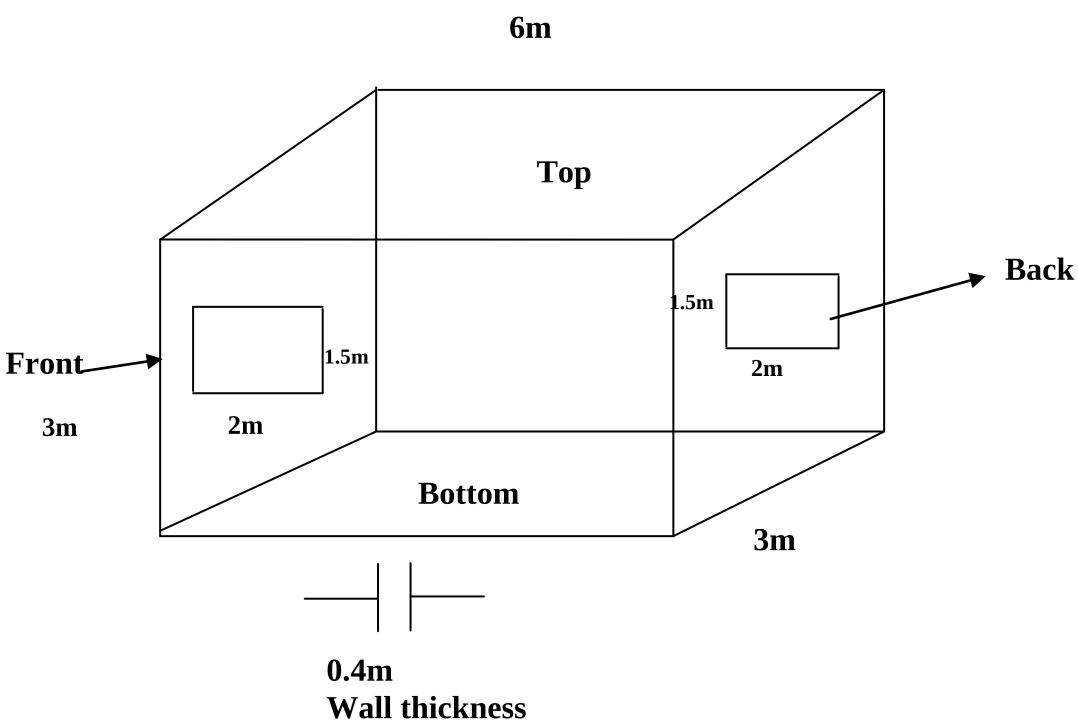

Fig. 3.1: Dimension of IHL oven
For top, $t_1 = 80^0$C, $t_2 = 35^0$C, E = 0.8, a = 2.8

$$Q_{Top} = 2.8\left(80 - 35\right)^{1.25} + 4.88 \times 0.8\left[\left(\frac{80+273}{100}\right)^4 - \left(\frac{35+273}{100}\right)^4\right]$$

$$Q_{Top}\ 326.343 + 3.904\left(155.274 - 89.992\right)$$

$$Q_{Top} = 326.343 + 254.861 = 581.204\ \text{kcal/m}^2\text{h}$$

$$\text{but}\ \ 1\,\text{kcal} = 4.184\,\text{kJ}$$

$$1\,\text{kcal/h} = 4.184\text{kJ/h} = \frac{4.184}{3600}\text{kW}$$

$$\therefore\ 1\,\text{kcal/h} = 1.162222 \times 10^{-3}\ \text{kW}$$

$$\therefore\ \ Q_{Top} = 0.6755\text{kW/m}^2$$

For side wall, $t_1 = 80^0$C, $t_2 = 35^0$C, E = 0.8 and a = 2.8. There are two sides with same dimension as the top. Therefore, the heat lost through side is twice that lost through top.

$$\text{Qside} = 2 \times 0.6755\ \text{kW/m}^2$$

$$= 1.351\,\text{kW/m}^2$$

For front & back, $t_1 = 80^0C$ $t_2 = 35^0C$, E = 0.8 and a = 2.8.

$$Q_{f\ ront} = 2.8\,(80-3)^{1.25} + 4.88 \times 0.8 \left[\left(\frac{80+273}{100} \right)^4 - \left(\frac{35+273}{100} \right)^4 \right]$$

$$Q_{f\ ront} = 326.343 + 254.861 = 581.204\ \mathrm{kcal/m^2h}$$

$$Q_{front} = 0.6755\mathrm{kW/m^2}$$

$$\text{But } Q_{front} = Q_{Back} = 0.6755\mathrm{kW/m^2}$$

$$Q_{Bottom} = 1.5\,(80-35)^{1.25} + 4.88 \times 0.8 \left[\left(\frac{80+273}{100} \right)^4 - \left(\frac{35+273}{100} \right)^4 \right]$$

$$Q_{Bottom} = 174.826 + 3.904\,(155.274 - 89.992)$$

$$Q_{Bottom} = 429.687\ \mathrm{kcal/m^2h}$$

$$Q_{Bottom} = 0.49939\ \mathrm{kW/m^2}$$

Table 3.3 shows the summary of oven wall losses.

Table 3.3: Estimation of oven wall losses

Location	**Area (m^2)**	**Heat flux (kW/m^2)**	**Heat loss (kW)**
Top	18	0.6755	12.159
Sides (2)	18	1.3510	24.318
Front	9	0.6755	6.080
Back	9	0.6755	6.080
Bottom	18	0.4994	8.989
			57.626

It should be noted that the production crew operates on two shift of 12 hours per shift with a break of 2 hours in between shift. That makes the total working hours per day to be twenty hours (20hrs/day).

Heat losses through the walls = 57.626 kW $\times$ 12 months
$\times$ 26 days $\times$ 20 hrs $\times$ 60 mins $\times$ 60 secs.
Heat losses through the walls = 1, 294.51 GJ

3.5.2 Radiation (opening) losses

The heat loss from an opening (in kcal/hr) can be calculated using the formula

$$Q = 488 \left(T/100 \right)^4 \times a \times A,$$ Trinks and Mawhinent (1967). - 3.8

Where: T = Absolute temperature (K)
A = Areas of opening (m^2)
a = Factor for total radiation.

See attached graph by Trinks and Mawhinnet (1967) for the estimation of factor of total radiation for various opening shapes. It depends on the ratio of the diameter or least width to the thickness of wall.

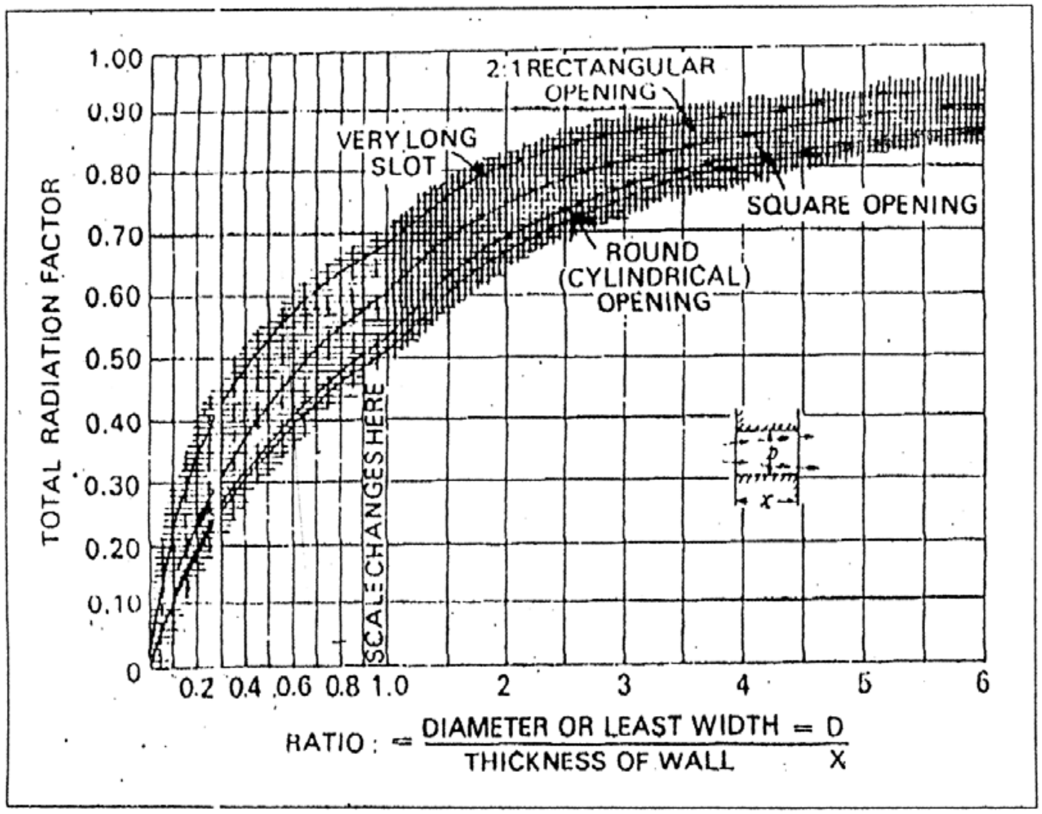

Fig. 3.2: Graph for estimation of factor of total radiation.

$$\frac{\text{Diameter}}{\text{Thickness of wall}} = \frac{D}{x} = \frac{2}{0.4} = 5$$

Ratio = - - - - 3.9

For a rectangular opening, the total radiation factor, a corresponding to a ratio of 5 is 0.85. See attached graph. The average temperature of the oven, t = 115^{0}C (388.15k)

Area of opening = 1.5 $\times$ 2 = 3m^2.

$$Q = 2\left[488\left(\frac{388.15}{100}\right)^4 \times 0.85 \times 3\right]$$ for inlet and outlet.

Q = 11.2274kW

But opening is made every quarter of an hour

:. Q = 2.8069kW.

Therefore, the heat losses due to opening for the period of audit are estimated to be:

Q = 2.8069 $\times$ (12month $\times$ 26 days $\times$ 20 hrs $\times$ 60min $\times$ 60sec)

Q = 63.054GJ

3.5.3 **Stack heat losses of oven**

A significant amount of heat is lost through the stack, providing an opportunity to further improve the process efficiency. The heat lost via the stack is calculated as:

$$Q_{stack} = M_{product}\ Cp_{stack\ gases}\ (\Delta T)_{stack} \quad - \quad - \quad - \quad - \qquad 3.10$$

where: $M_{product}$ = mass flow rate of stack gases

$Cp_{stack\ gases}$ = Specific heat capacity of stack gases

ΔT = stack temperature difference.

The stack gases mass flow rate could be evaluated from the combustion analysis of diesel fuel using air as the oxidant. This could be achieved as follows:

(a) **Combustion analysis of diesel fuel**

The average chemical formula for diesel fuel is $C_{12}H_{23}$. The chemical equation for the stoichiometric combustion of diesel using oxygen as the oxidant is,

$$4\,C_{12}\,H_{23} + 710_2 \rightarrow 48\,CO_2 + 46H_2o$$

Stoichiometric Air/Fuel Ratio (SAFR) = $\dfrac{\text{Mass flow rate of air}}{\text{Mass flow rate of diesel}}$ ……………………3.11

For gravimetric analysis, the percentage composition of oxygen by mass is 23.3% while Nitrogen is 76.7%.

Mass of oxygen = 71 (32) = 2, 272kg.

Mass of air = $\dfrac{2,272}{0.233} = 9,751.073\text{kg}$

Mass of diesel = 4 (12 $\times$ 12 + 23 $\times$ 1) = 668kg

$$\therefore SAFR = \frac{\text{Mass flow rate of air}}{\text{Mass flow rate of diesel}} = \frac{9,751.073}{668} = 14.5974$$

Now, assuming an Actual Air/Fuel Ratio of 20,

AAFR = $\dfrac{\text{Mass flow rate of air}}{\text{Mass flow rate of diesel}} = 20$

but mass flow rate of diesel = $\dfrac{\text{mass of diesel consumed}}{\text{oven firing time}}$ - 3.12

Mass flow rate of diesel = $\dfrac{319,328.8}{12 \times 26 \times 20 \times 3600}$ = 0.014215 kg/s

:. Mass flow rate of air = 20 $\times$ mass flow rate of diesel

= 20 $\times$ 0.014215

= 0.2843kg/s

But mass flow rate of stack gases (product) = mass flow rate of diesel + mass flow rate of air

= 0.014215 + 0.2843

= 0.298515kg/s

The equation for the combustion of diesel using air as the oxidant is,

$$4\,C_{12}\,H_{23} + 71\left(0_2 + {}^{79}\!/_{21}\,N_2\right) \rightarrow 48CO_2 + 46\,H_20 + 71\left(\frac{79}{21}\right)N_2$$

For 1 kmol of diesel, the equation becomes

$$C_{12}\,H_{23} + 71\!\!\diagup\!_4\left(0_2 + 79\!\!\diagup\!_{21}\,N_2\right) \rightarrow 12CO_2 + 23\!\!\diagup\!_2\,H_2 0 + 71\!\!\diagup\!_4\left(\frac{79}{21}\right)N_2$$

Where oxygen is 21% by volume in air and nitrogen is 79% volume in air.
For an actual air/fuel ratio (AAFR) earlier assumed,

$$\frac{\text{AAFR}}{\text{SAFR}} = \frac{20}{14.5974} = 1.3701$$

$$C_{12}\,H_{23} + 1.3701\left(71\!\!\diagup\!_4\right)\left[O_2 + \frac{79}{21}N_2\right]$$

$$\rightarrow 12\ CO_2\ +\ 23\!\!\diagup\!_2\ H_2O + 1.3701\left(\frac{71}{4}\right)O_2\ +\ 1.3701\left(\frac{71}{4}\right)\left(\frac{79}{21}\right)N_2$$

(b) **Production analysis**

Table 3.4 shows the combustion products analysis for the determination of the specific heat capacity of the stack gases.

Table 3.4: Combustion products analysis

Consistent	**Mass of products (kg) per kmol of fuel (diesel)**	$\frac{m_i}{\sum m_i}$
Co_2	528	0.1296
H_2o	207	0.0508
O_2	778.2168	0.1910
N_2	2,561.6303	0.6286
	4,074.8471	1.000

$$Cp_{stack} = \frac{\text{Mass of } CO_2}{\sum m_i}Cp_{\ Co_2} + \frac{\text{Mass of } H_2O}{\sum m_i}Cp\ H_2O +$$

$$\frac{\text{Mass of } O_2}{\sum m_i}CpO_2 + \frac{\text{mass of } N_2}{\sum m_i}Cp_{N2} \qquad - \qquad - \qquad 3.13$$

The stack mean temperature = $\frac{(27+273.15)+(115+273.15)}{2}$

$= 344.15k$

The specific heat capacity of the products of combustion taken at the stack mean temperature of 344.15K from thermodynamic properties table is as follows. This is interpolated between 325K and 350K.

$$\frac{350\ -\ 325}{344.15 - 325} = \frac{\text{unknow } - L}{F\ - L}$$

Unknown = 0.766 (F – L) + L

Where L = Last reading, F = First reading. This is shown on Table 3.5.

Table 3.5: Specific heat capacity (Cp_s) of combustion products at stack mean temperature

Product	**Cp_s at 350K**	**Cp_sat stack mean Temp (344.15K)**	**Cp_sat 325K**
Co_2	0.895	0.889	0.871
H_2O	1.880	1.878	1.871
O_2	0.928	0.927	0.923

N_2	1.0407	1.0407	1.040

$$\therefore Cp_{stack} = (0.1296)(0.889) + (0.0508)(1.878) + (0.1910)(0.927) + (0.6286)(1.0407)$$

$$Cp_{stack} = 1.0419 kJ/kgK$$

$$\therefore Q_{stack} = M_{product} \times Cp_{stack} \times \Delta T$$

$= 0.2985 \times 1.0419 \times (115 - 27)$

$= 27.37 kW$

Heat lost through $= 27.37 \times 12 \times 26 \times 20 \times 3600$

Stack for the period of audit

≫ = 614.84GJ

3.6 Energy saving opportunities

For improvement of the plant energy utilization and conservation, different fuel economy measures can be employed. Some of these measures are:

1. Control of furnace/oven draught.
2. Installing more efficient burners.
3. Proper heat distribution inside oven.
4. Improved oven insulation.
5. Reducing heat losses from oven opening.

3.6.1 Maximum heat recoverable from stack

The gases leaving the stack are at a high temperature and therefore high enthalpy. The gases lost to the atmosphere represent a huge loss of energy. Some of this energy can be recovered by passing the hot gases from the stack through a heat exchanger where the heat transferred from the gases will be used to raise the temperature of the pool circulating water for effective wash of the crumb rubber.

Assuming a heat exchanger effectiveness (Thermal ratio) of 0.75 is introduced between the circulating pool water and the stack, then these savings will be made.

$$E = \frac{\text{Temperature rise in ciruclating water}}{\text{Max temperature difference available}} \quad - \quad - \quad - \quad - \quad - \quad 3.14$$

$$E = \frac{Tw_2 - Tw_1}{Tstack - Tw_1}$$

Where: E = Thermal ratio, assumed to be = 0.75

Tw_2= Temperature of circulating pool water after heat exchanger.

Tw_1= Temperature of water before heat exchanger measured to be 16^0C.

Tstack = Temperature of the stack gases (115^0C).

$$0.75 = \frac{Tw_2 - 289.15}{388.15 - 289.15}$$

Tw_2= 363.4k (90.25^0C).

This implies that the crumb rubber will now be fed into the oven at a new temperature of 90.25^0C.

$$\begin{array}{llll} \text{Heat energy} & = \text{Heat recived by} & - & \text{Heat received} \\ & \text{crumb rubber} & & \text{by crumb rubber} \\ \text{Saved by oven} & \text{without heat exchanger} & & \text{with heat exchanger} \end{array} \quad - \quad -3.15$$

$$\gg \quad = M_{CR} \times Cp_{CR}(t_2 - t_1) - M_{CR} Cp_{CR}(t_2 - t_{w_2})$$

≫ $= M_{CR} \times Cp_{CR}\left[(t_2 - t_1) - (t_2 - t_{w_2})\right]$

Heat energy = 0.4667 × 1880 $[(115-27)-(115-90.25)]$ saved by oven
≫ = 877.396 (88-24.75)
= 56, 127.797J/s
Heat energy saved = 56, 127.797 × 12 × 26 × 20 × 3600
by oven for the period of audit
≫ = 1, 260.85GJ

3.7 **Cost analysis of energy saved**

Since the oven is solely run on diesel fuel, heat energy saved in the oven will be attributed to the diesel fuel. The total energy consumption of diesel fuel for the one year period of audit was 14,689.127GJ. This amounted to N37, 338.000. If the suggestion of the introduction of heat exchanger is carried out, 1, 260.85GJ of energy will be saved for the period. This will amount to N3,204, 929.56. On a daily average, N10,239.39 will be saved. This is about 97.5 litres of diesel in a day. The saving will have effect on both the specific energy cost and the specific energy consumption.

New specific energy cost = $\dfrac{\text{old cost - savings}}{\text{Total production output}}$ - -3.16

≫ = $\dfrac{56,914,940 - 3,204,929.56}{4,104.474}$

New specific energy cost = N13, 086/ton or N13.086/kg.

Similarly, the specific energy consumption based on the change made will be:

New specific energy consumption = $\dfrac{\text{Total Energy Consumed - Savings made}}{\text{Total Production output.}}$ - - - - - - - - - - 3.17

≫ = $\dfrac{17,641.343 - 1,260.85}{4,104.474}$

New Specific Energy Consumption = 3.99GJ/ton or 3.99MJ/kg.

IV. Results and Discussions

4.1 **Electrical consumption**

From the data collected from the company, the annual electricity consumption in the plant and the cost is analyzed in Table 4.1.

Table 4.1: Annual electrical energy consumption analysis

Month (2014)	Reading (kWh)	Cost per kWh (N/kWh)	Cost (N) x1000	Fixed charge (N)	VAT (N) x 1000	Monthly Total cost (N) x 1000
JAN-14	65,460	19.76	1,293.49	155,923	72.47	1,521.88
FEB-14	185,100	19.76	3,657.58	155,923	190.68	4,004.18
MAR-14	63,000	19.76	1,244.88	155,923	70.04	1,470.84
APR-14	101,800	19.76	2,011.57	155,923	108.37	2,275.86
MAY-14	117,900	19.76	2,329.70	155,923	124.28	2,609.90
JUN-14	47,300	19.76	934.65	155,923	54.53	1,145.10
JUL-14	39,000	20.75	809.25	155,923	48.26	1,013.43
AUG-14	61,900	20.75	1284.43	155,923	72.02	1,512.37
SEPT-14	38,900	20.75	807.18	155,923	48.16	1,011.26
OCT-14	37,100	20.75	769.83	155,923	46.29	972.04
NOV-14	36,200	20.75	751.15	155,923	45.35	952.42

DEC-14	26,400	33.33	879.91	155,923	51.79	1,087.62
TOTAL	820,060	Average 21.30	16,773.62	1,871,076	932.24	19,576.94

From Table 4.1, the annual electrical energy consumption is 820,060kWh. This was delivered to the plant at a total cost of N19,576,940. Also from Table 4.1, the total monthly cost of electrical energy consumption was calculated as N19,576,940

4.2 **Fuel (diesel) consumption**

The diesel consumed are stored in a tank calibrated in cm. 1cm equivalent is 112 litres. The cost per litre for the period of audit is N105.00. The monthly quantity of diesel fuel was converted to kg. The total cost of diesel fuel for the period of audit was also computed. These are shown in Table 4.2

Table 4.2: Annual diesel fuel consumption analysis.

Month (2014)	**Tank reading (cm)**	**Equivalent liters**	**Mass of diesel (kg)**	**Cost per litre(N)**	**Total cost x 1000 (N)**
JAN-14	220	24,640	22,126.72	105	2,587.20
FEB-14	524	58,688	52,701.82	105	6,162.24
MAR-14	465	52,080	46,767.84	105	5,468.40
APR-14	316	35,392	31,782.02	105	3,716.16
MAY-14	336	37,632	33,793.54	105	3,951.36
JUN-14	133	14,896	13,376.61	105	1,564.08
JUL-14	178	19,936	17,902.53	105	2,093.28
AUG-14	191	21,392	19,210.02	105	2,246.16
SEPT-14	166	18,592	16,695.62	105	1,952.16
OCT-14	175	19,600	17,600.80	105	2,058.00
NOV-14	190	21,280	19,109.44	105	2,234.40
DEC-14	281	31,472	28,261.86	105	3,304.56
TOTAL	3,175	355,600	319,328.8	Average 105	37,338

4.3 **Energy consumption of cost**

The monthly energy input to the plant from the two sources of energy outlined above was calculated as follows:
For Diesel: Calorific value = 46.0 MJ/kg.
For Electricity (BEDC): Calorific value = 3.60 MJ/kWh

January Energy Consumption

(a) Diesel: Energy consumed = 22, 126.72 kg × 46 MJ/kg
= 1,017, 829.12MJ
See Table 4.2

(b) Electricity: Energy consumed = 65, 460 kWh × 3.6MJ/kWh
= 235,656MJ
= 235.656 GJ
See Table 4.1.

February Energy Consumption

(a) Diesel: Energy consumed = 52, 701.82 × 46
= 2, 424, 283.72 MJ

(b) Electrical: Energy consumed = 185,100 × 3.6
= 666, 360MJ
= 666.36GJ and so on.

The energy consumption for the two sources of energy for the period of audit is shown in Table 4.3. Also included in Table 4.3 is the production output for the period of audit.

Table 4.3: Energy consumption/production output

MONTH (2014)	Electricity (GJ)	Diesel(GJ)	Total Energy (GJ)	Production output (Metric Tonne)
JAN-14	235.656	1,017.829	1,253.485	839.825
FEB-14	666.360	2,424.284	3,090.644	719.075
MAR-14	226.800	2,151.321	2,378.121	733.145
APR-14	366.480	1,461.973	1,828.453	350.665
MAY-14	424.440	1,554.503	1,978.943	304.255
JUN-14	170.280	615.324	785.604	81.235
JUL-14	140.400	823.516	963.916	202.044
AUG-14	222.840	883.661	1,106.501	183.680
SEPT-14	140.040	767.999	908.039	145.880
OCT-14	133.560	809.637	943.197	159.005
NOV-14	130.320	879.034	1,009.354	166.565
DEC-14	95.040	1300.046	1,395.086	219.100
TOTAL	2,952.216 (16.73%)	14,698.127 (83.27%)	17,641.343	4,104.474

From Table 4.3, the minimum amount of energy was consumed in the month of June, 2014. This was as a result of a fall in the production output. Table 4.3, also reveals that the total amount of energy consumed (for both sources of energy) and the total production output are 17, 641.343GJ and 4, 104.474 tons respectively.

4.4 Energy performance result of plant

The two main performance indicators used in a production plant will be used in evaluating the plant based on the data collected during the one year period. These are:

Specific energy consumption (GJ/TON)

This is the total energy consumed per unit of production (ton or kg).

$$\text{Specific energy consumption} = \frac{\text{Total energy consumed (GJ)}}{\text{Total production output (kg)}} \quad - \quad -4.1$$

From Table 4.4, the total energy consumed is 17,641.343GJ while the total production output is 4, 104.474 tons.

$$\text{Specific energy consumption} = \frac{17,641.343\,\text{GJ}}{4,104.474\,ton}$$

$$= 4.298 \text{ GJ/Ton or}$$
$$= 4.298\text{MJ/kg.}$$

Specific energy cost (n/ton)

This is the cost of energy required to produce unit ton of crumb rubber.

$$\text{Specific energy cost} = \frac{\text{Total energy cost (₦)}}{\text{Total product output (Ton).}} \quad - \quad - \quad -4.2$$

From Table 4.4, the total energy cost of the plant for the period of audit is N56, 914, 940.

$$\text{Specific energy cost} = \frac{\text{N56,914,940}}{\text{4,104.474 Ton}}$$

= N13, 866.56/ton or
= N13.87/kg

Summarily, to produce 1 ton of crumb rubber in Imoniyame Holdings Limited Ughelli, about 4.298GJ of energy is required at a cost of N13,866.56/ton. The result is shown in Table 4.4.

Table 4.4: Energy efficiency performance result

Total energy consumed	17, 641.343GJ
Total cost of energy consumed	N56,914,940
Total production output	4,104.474 tons
Specific energy consumption	4.298GJ/ton of crumb rubber

Specific energy cost	N13,866.56/ton of crumb rubber

From the above analysis, reasonable cost is spent on the product of crumb rubber. In order for the company to be competitive in its market, a lot of attention should be paid on energy cost reduction by management and personnel.

Fig 4.1 and 4.2 show the energy consumption and energy cost pie chart respectively.

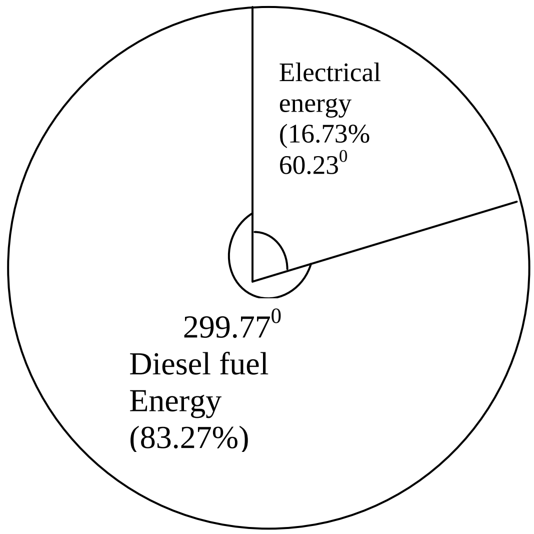

Fig 4.1: Energy consumption chart

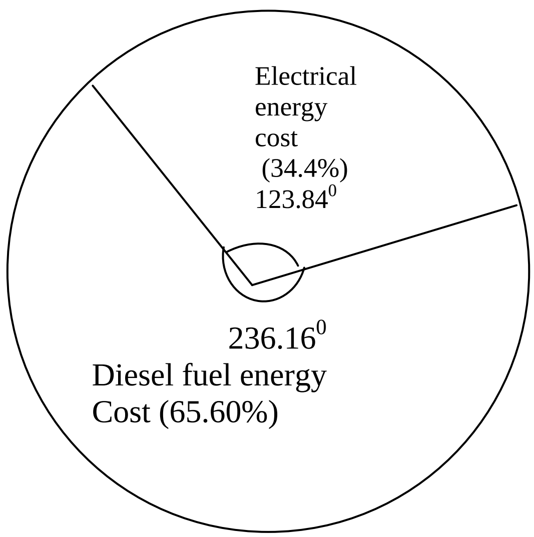

Fig. 4.2: Energy cost chart.

4.5 Diesel consumption rate of various burners

Table 4.5 gives the records of the diesel consumption of the burners in the various production lines. The 2G and 4G burners have a rating of 11kg/h. An assumption of 20 hrs operation per day was used for the audit.

Table 4.5: Diesel Fuel consumption of the various burners of the production lines

LINES	Rating of 2G and 4G (kg/h)	2G and 4G (20 hrs per day)	2G and 4G kg/month (26 days)	2G and 4G kg/yr (12 months)
A &B	11.00	220.00	5,720.00	68,640.00
C	11.00	220.00	5,720.00	68,640.00
D	11.00	220.00	5,720.00	68,640.00
			17,160.00	205,920.00

Energy Consumed by Burners = mass of diesel/yr ×
Heating value of diesel.
= 205, 920 kg/yr × 46 MJ/kg
= 9, 472, 320 MJ/yr
= 9, 472.32 GJ/yr

Therefore, the energy consumed by the oven for the one year period of audit is 9, 472.32GJ.

4.6 Sankey diagram of IHL oven

A Sankey diagram is drawn from the oven analysis done earlier. Fig. 4.3 shows the Sankey diagram of IHL oven operations.

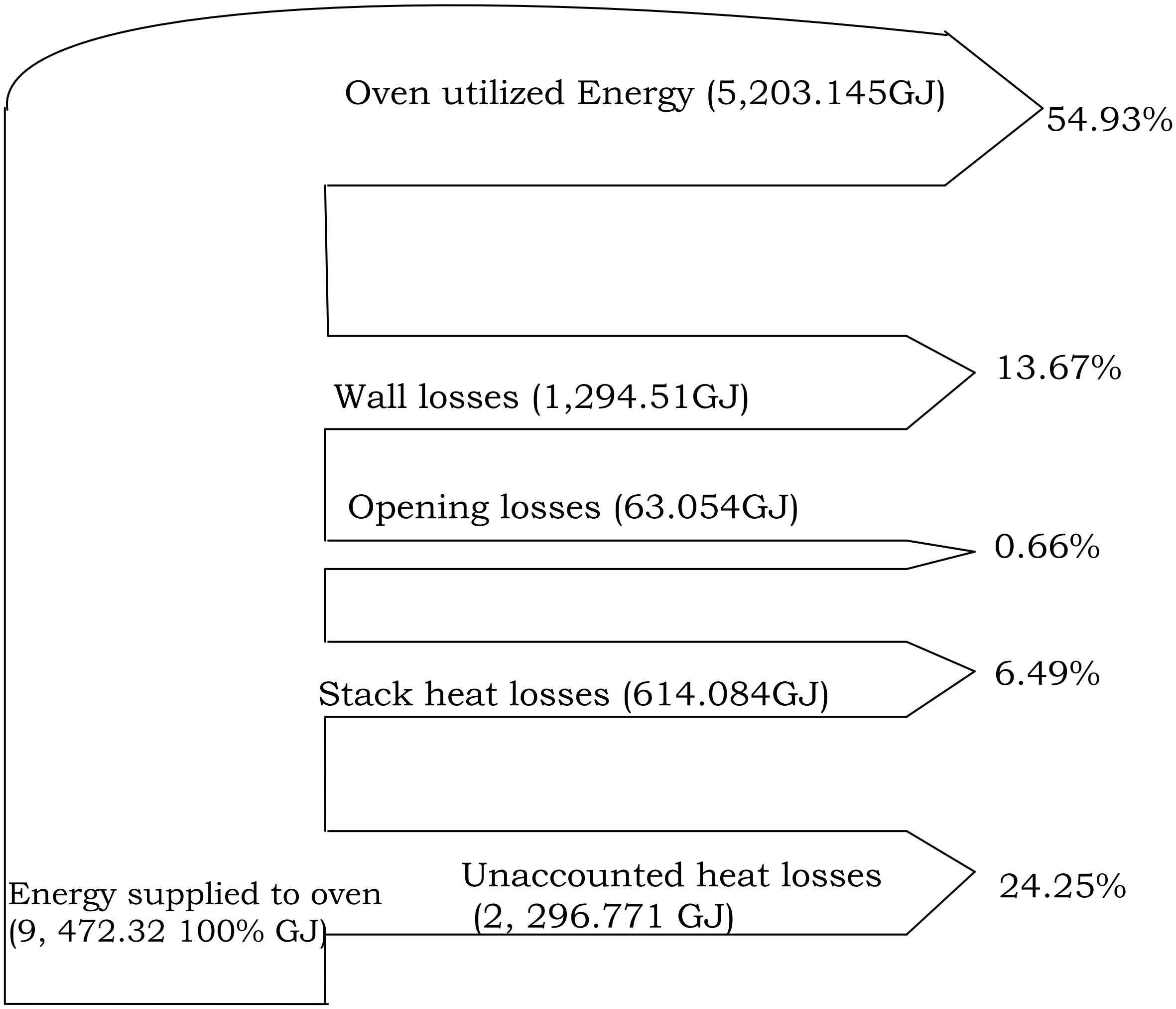

Fig. 4.3: Sankey diagram of IHL oven operations

4.7 **Energy pathway of IHL**

This is the energy distributed to various sections of the plant for the period of audit. This is shown in fig: 4.5

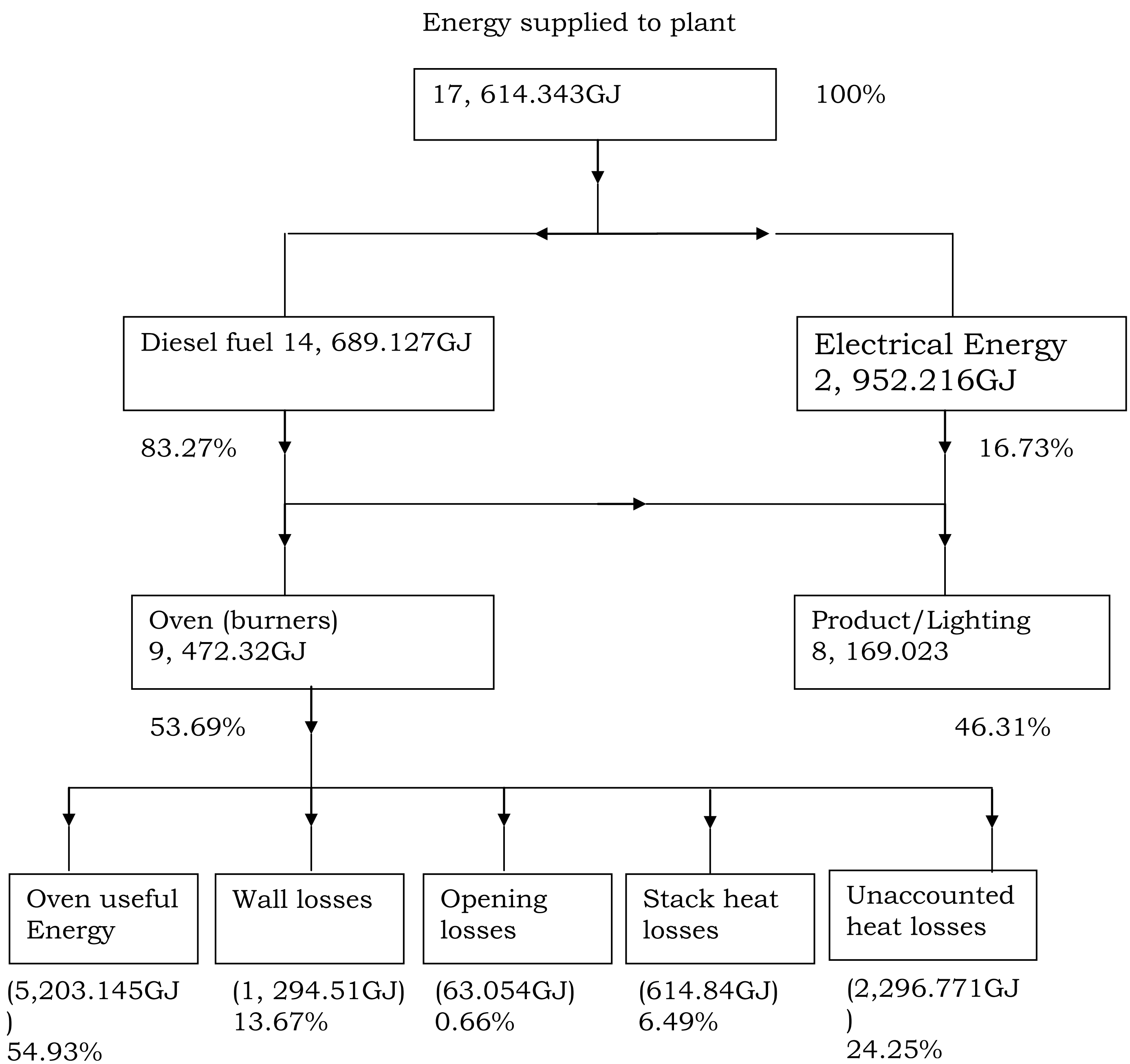

Fig. 4.5: Energy pathway of IHL.

4.8 Discussion

Crumb rubber production is an energy intensive process. Efficient use of energy is necessary to ensure that crumb rubber manufacturers like Imoniyame Holdings Limited Ughelli, remain competitive. It was ascertained in this audit that the oven with burners attached to it is the largest energy consumer in the crumb rubber processing plant. Periodic evaluation of the oven's energy efficiency can potentially pay huge dividend through reduced energy usage. With significantly higher prices of diesel fuel and electricity, reducing energy use will become increasingly important. The procedure developed through this work can be extremely beneficial by providing a structured approach for assessment of the oven's energy efficiency and the identification of potential system improvements.

4.9 Observations

From the result and findings of the energy audit carried out in the crumb rubber factory, the following were observed.

(1) The total energy consumed in the entire plant over the one year period (Jan. 2014 to Dec. 2014), is 17,641.343GJ. Electrical energy was 2,952.216 GJ, which is 16.73% of the total energy while diesel fuel was 14,689.127GJ representing 83.27% of the total energy. This shows that the plant depends more on diesel fuel.
(2) The total cost of energy in the plant for the period (Jan. 2014 to Dec. 2014) of audit was N56,914, 940 of which diesel fuel is 65.6% while Electrical accounts for 34.4%.
(3) The total production output for the period (Jan. 2014 to Dec. 2014) of audit was 4, 104.5 tons of crumb rubber.
(4) The burners in the oven are the most energy intensive units in the plant. 9, 472.32GJ of energy which is 53.6% of the total energy consumed was by the burners (oven). This unit hold the greatest energy saving potential in the plant.
(5) It was also observed that notable amount of electrical energy could be saved by developing an overall motor inventory and replacement plan in the plant.

4.10 Efficiency of crumb rubber production

The quality of crumb rubber in Imoniyame Holdings Limited, Ughelli is SIR3. The plant specific energy consumption was 4.298GJ/ton which is also 4.298MJ/kg of crumb rubber. This is relatively high compared to 2.63MJ/kgof crumb rubber of quality SIR 3 carried out by Utomo et al. (2008). Thus, there is still need to further reduce the specific energy consumption of the Imoniyame Holdings Limited crumb rubber. This could be done by utilizing the stack heat losses with the aid of heat exchanger as suggested. When this is done, the specific energy consumption will be reduced to 3.99MJ/kg. This compared to 2.63MJ/kg of crumb rubber, of same quality (SIR3) carried out by Utomo et al (2008) will be seen as fair.

The specific energy cost was computed to be N13.87/kgof crumb rubber. This could be reduced to N13.086/kg of crumb rubber by the introduction of heat exchanger to recover the heat lost through the stack. This could also be achieved by the reduction in price of diesel fuel and amount of kWh of electricity or outright conservation of the sources of energy. The 4,104.475 tons of crumb rubber produced during the period of audit (Jan. 2014 to Dec. 2014) can be improved on by implementing the following measures:

(1) Availability of fund for raw materials (natural rubber latex).
(2) Increase in export demand.
(3) Improved effective production process.

V. Conclusion and Recommendation

5.1 Conclusion

The energy audit of Imoniyame Holdings Limited has been done successfully. The energy pathway showing amounts and percentages of energy spent in various section were also shown.

From the audit, the total amount of energy supplied to the plant was 17, 641.343GJ. Diesel fuel which was 83.27% of the total energy was 14, 689.127GJ while electrical energy from BEDC was 2,952.216GJ representing 16.73% of the total energy supplied. The total cost of energy under the period of audit (Jan. 2014 to Dec. 2014) was N56,914,940. Of this amount, N19,576,940 representing 34.4% of the total cost was spent on electrical energy while N37,338,000 representing 65.6% of the total cost was spent on diesel fuel. The total tonnage produced was 4,104.475 tons for same period. The audit also reveals that the specific energy consumption for a crumb rubber production in Imoniyame Holdings Limited is 4.298MJ/kg. The specific energy cost was N13.87/kg of crumb rubber.

From the oven analysis, the efficiency of the oven was discovered to be 54.93%. The oven section consumed 9,472.32GJ. This is about 53.69% of the total energy supplied to the plant for the period of audit. The production and lighting sections consumed 8,169.023GJ. This is about 46.31% of the total energy supplied to the plant for the period of audit. The Sankey diagram of Fig. 4.3 reveals that 2,296.771GJ of energy representing 24.25% of the total energy supplied to the oven was unaccounted for. This could be due to oven design error, errors in measurement, calculation and evaluation or errors due to human operation. From the first law of thermodynamics which is the principle of conservation of energy, a huge improvement can still be made.

5.2 Recommendations

From the energy audit carried out on Imoniyame Holding Limited Ughelli (a crumb rubber processing factory), the following recommendations are suggested.

1. The heat lost through the stack should be recovered by introducing heat exchanger between the stack and the pool circulating water. This will help to wash the crumb rubber cleaner and faster and at same time preheat the crumb rubber before entering the oven. This will reduce the heat required from the oven, increase its life span, and improve its efficiency. When this is done, the following improvement will be made.

i. A daily savings of N10,239.39 will be made. This will amount to N3,204,929.56 in a year. It will reduce the total cost of energy from N56,914,940 toN53,710,010.44 within the one year period of audit.
ii. The specific energy consumption will drop from 4.298 MJ/kg to 3.99MJ/kg of crumb rubber.
iii. The specific energy cost will also be reduced from N13.87/kg to N13.086/kg of crumb rubber.

2. Different metering system should be adopted to separate the energy consumption of the production lines from lighting. This will help to know the exact amount of energy required per production line and the base load energy (lighting) required when there is no production. Separation will reveal energy wastage areas.
3. The diesel supply lines to the 2G and 4G burners should be separated and different meters attached to know the energy consumed by different burners.
4. Appropriate energy record keeping should be practised to enable this kind of audit done over a longer period of time. A good average will give a more accurate result that will influence management decision in terms of policy making.

List of tables

Nomenclature

Symbol	**Description**	**Unit**
A	Area	m^2
a	Factor for total radiation	
Cp	Specific heat capacity	kJ/kgK
CP_{CR}	Specific heat capacity of crumb rubber	kJ/kgK
E	Emissivity	
GCV	Gross calorific value	kJ/kg
M	Mass	kg
$\dot{M}$	Mass flow rate	kg/s
NPI	Normalized Performance Indicator	GJ/m^2
Q	Quantity of Heat	kJ
T	Absolute temperature	K
Δt	Temperature difference	K

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