ENERGY UTILIZATION AND SAVING OPPORTUNITIES IN TEXTILE INDUSTRIES: CASE STUDY OF RIVATEX EAST AFRICA LTD, KENYA

BY

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DECLARATION

Declaration by the Student:

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DEDICATION

I dedicate this work to my family, parents and my siblings for encouragement and moral support they gave me and also to my supervisors for their guidance to ensure success of my research work.

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ABSTRACT

In textile manufacturing, energy is a major contributor to production cost besides labour and raw materials. Thus, for textile industries to remain competitive, it is imperative that they develop energy management strategies for reduction of energy cost. Therefore, the main aim of this research was to assess the energy utilization in the textile factory at Rivatex East Africa Limited, Kenya and identify energy saving and conservation measures that would help reduce energy intensity and consequently lower the production cost. The specific objectives were to; analyze the energy utilization in the factory, evaluate the performance of energy utility systems and equipment, determine the potential energy savings and formulate an energy model to optimize energy utilization in the factory. Standard measurement techniques stipulated in the energy efficiency assessment manual by Association of Energy Engineers (AEE) were adopted to investigate the energy utilization and performance of high energy consuming utility systems and equipment such as compressed air systems, boilers, motors, lighting systems and steam distribution systems. Boiler flue gas analysis test, air compressor air leak test, heat loss analysis for steam distribution system, motor load assessment and load variation trends in air compressor experiments were performed. Based on established efficiency of utility systems and equipment, energy saving and conservation measures were identified. Further, a mathematical model was developed using linear programming for energy utilization and optimization. Energy utilization analysis showed that high electricity consumption occurs in spinning process 527,300 kWh/year (48%), followed by weaving process 287,700 kWh/year (26%), wet processing 247,300 kWh/year (22%) and other (boiler) 114,200 kWh/year (4%). Performance evaluation of energy utility systems and equipment found wood fire-tube boiler efficiency to be 17.35%, thermo-boiler 86.1%, air compressor 75.48% and motors power factor 0.28. The study found potential savings in electric energy to be 367,784 kWh/year, wood fuel savings 1,219 tones/year and furnace oil savings 22,275 litres/year. For the high energy consuming systems and equipment, the result indicated an overall energy cost saving potential of 31.6% with an average simple payback period of 2 years. Developed energy model displayed yearly energy cost reduction of 5.5% leading to savings of Kshs. 2 million per year. In conclusion, the results show that a significant potential exists for energy saving in textile manufacturing process and that application of linear programming models could help in identifying optimal energy saving routes in textile processing. The study recommends regular performance evaluation of high energy consuming utility systems and equipment to be conducted for early detection of energy losses to minimize energy expended in the plant.

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SYMBOLS, ABBREVIATIONS AND NOTATIONS

BEE	Bureau of energy efficiency
CFL	Compact fluorescent lamp
EnMS	Energy management systems
EPA	Environmental protection agency
ERC	Energy regulatory commission
GCV	Gross calorific value
GHG	Greenhouse gas
HID	High intensity discharge
Ksh	Kenya shilling
KVA	Kilo Volt Ampere
LSHS	Low Sulphur Heavy Stock
PEL	Power and energy logger
PF	Power factor
PPM	Parts per million
RMS	Root mean square
SEC	Specific energy consumption
SPP	Simple payback period
THD	Total harmonic distortion

CHAPTER ONE

INTRODUCTION

1.1 Background and Motivation

Energy is a major contributor to production cost besides labour and raw materials in textile manufacturing. In general, the textile industry is not considered an energy intensive industry compared with other industries like metal smelting or the raw chemical materials and chemical products manufacturing industry. However, the textile industry comprises a large number of plants, which together consume a significant amount of energy (Wang et al., 2017). In general, energy in the textile industry is mostly used in the forms of electricity, as a common power source for machinery, cooling and temperature control systems, lighting, office equipment and oil, LPG; coal; or natural gas as a fuel for steam generators (Ozturk et al., 2020).

Energy efficiency and conservation are critical for textile manufacturing industries to remain competitive both in local and global markets while making profits (Bravo et al., 2022). The textile industry retains a record of the lowest efficiency in energy utilization and is one of the major energy consuming industries. There are significant loses of energy within textile plants and around (36%) of energy input is lost onsite. Motor drawn systems constitute 13%, steam distribution system (8%), boiler systems (7%), equipments (7%) and motor losses (1%) of the onsite energy waste (Nagaveni et al., 2019).

Energy constitutes between 5 -10% of the total production cost in textile industries in developed countries but is far higher in developing countries for instance China (8%), Brazil (5%), Turkey (9%), USA (6%) and India (12%). The cost of energy often comprises the third or fourth highest cost of the overall product cost in developed countries (Khude, 2017; Bantelay et al, 2020). Vietnam's Ministry of Industry and

Trade (MOIT) estimates that energy costs in the Textile & Garment industry are approximately 12% of the total production costs, or close to US$ 3 billion per a year. However, there remain significant opportunities to reduce energy costs by improving energy efficiency through a combination of equipment replacement, usage management, and other measures, representing savings up to 30% as estimated by MOIT.

In developing countries energy cost represent between 15-35% of the total production cost in textile industries. Bantelay et al., 2020 found that cost-share of energy in Ethiopian cotton textile industries accounts for an average of 16.01% of the total production cost of a cotton product and it is the second-highest cost of a product next to raw material. In Kenya, energy cost accounts up to 25% of Kenyan textile firms' operating costs (Konishi et., 2016) and it is sometimes as high as 40% of the unit cost of manufacture according to Kenya association of manufacturers (KAM,2018) while in Rivatex East Africa Ltd, Kenya it constitutes 27% of the total cost of production.

Rivatex East Africa Ltd is one of the biggest composite textile mills in Kenya. The Company is located about 1.5 kilometers from Eldoret town along the Eldoret, Kapsabet road. Given that this industry is energy intensive consuming approximately 1,500,000 kWh annually, it is very important to optimize its energy consumption and hence energy conservation. It is very essential to minimize the energy cost and energy consumption for the textile industry to reduce the cost and to rival. Increasing global competition puts high demands on the industry to reduce the cost of production.

Therefore, the aim of the study was to assess energy utilization, identify energy saving opportunities and develop an energy model to optimize the energy utilization in the plant.

1.2 Statement of the Problem

The high cost of energy, which accounts for up to 35 % of the overall cost of running an industrial operation in East Africa's largest economy, continues to cause Kenya to lose their competitive edge in international markets. This is mostly attributed to high energy costs (Owiro et al., 2015).The manufacturing sector is negatively affected by high energy costs that translate to high cost of production thus resulting in expensive end products rendering Kenyan manufactured goods uncompetitive in the global market (Wangila, 2008). This problem of high energy cost is further aggravated by lack of a constant reliable supply of raw materials that largely affects agro-processors as they have to import raw materials to meet their input needs (Chahenza, 2017).

The textile and garment industry is one of the manufacturing industries that has been impacted severely. During the decade of 1980, it was the most important manufacturing sector in the country and the fifth most important source of foreign exchange gains. Energy expenses account for 35% of total production costs in Kenya, whereas in India, same prices only account for 16% of total production costs (Fukunishi, 2012). Rivatex East Africa is one of the leading textile industries in Kenya but due to high energy costs which represent 27% of the total production cost, the industry has remained uncompetitive hence relying on external support from Kenyan government to meet operating costs (Kabissa et al., 2021). In the face of rising energy costs and stiff competition in textile sector, there is a pressing need to conserve energy by properly managing the available resources. The study intends to investigate energy utilization and to identify energy saving and conservation measures that exist in Kenya’s textile industry taking a case study of Rivatex East Africa Limited.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of the study was to investigate energy utilization in Rivatex East Africa Ltd, Kenya and to identify the potential energy saving and conservation measures.

1.3.2 Specific Objectives

1) To investigate energy utilization in the textile manufacturing plant.
2) To evaluate energy efficiency of energy utility systems and equipment and identify energy saving and conservation measures that can help improve energy utilization at the plant.
3) To develop an energy model to optimize the energy utilization in the plant.

1.4 Justification of the Study

Kenya has 52 textile mills, of which only 15 are currently operational and operate at less than 45 percent of total capacity due to high energy cost (Malicha & Njoroge, 2020). Due to the challenge, Kenya currently relies heavily on imported new and second hand textiles and clothing from the east and west (Wanduara, 2018).

High cost of energy has made Kenyan manufactured textile products uncompetitive both in local and global markets. Energy inefficiency contribute significantly to high cost of energy and studies reveal that 39% of the energy input to the textile industry is lost on site. Motor systems have the highest proportion of on-site energy waste (15%), steam distribution systems at 9%, boiler losses at (7%) and equipment losses (8%) (Cevallos & Ponce, 2022).

Therefore, research on energy utilization in Rivatex East Africa limited provides necessary information to the case study industry on ways to deal with rising energy costs incurred by the industry and any other industry with similar processes. Reducing energy use, reduces energy costs resulting in a financial cost saving.

In addition, the study will contribute towards policy making on energy management matters by the government and industrial sector. Identified energy saving opportunities will assist industries improve energy efficiency hence reduced energy cost enabling textile plants to be competitive both locally and globally. Also, the study will form basis for future studies on other textile plants and industries with similar manufacturing processes.

1.5 Scope of the Study

This study was restricted to energy intensive utility systems and equipment at Rivatex East Africa Limited which include motors systems, steam distribution systems, compressed air systems, boiler systems and lighting systems.

1.6 Research Questions

(i) How is energy utilized in the textile plant?

(ii) What is the efficiency of energy utility systems and equipment and what are some of the energy saving and conservation measures that can help improve energy utilization in the plant?

(iii) How can energy utilization be enhanced in the plant?

1.7 Outline of the Research

This research comprises of six chapters. It covers the introduction, literature review, methodology, results and discussion, energy optimization model and conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents brief history of Rivatex East Africa Limited. Also, textile manufacturing processes, energy use in textile industries and energy saving opportunities available in air compressor system, lighting system, steam distribution system, boiler and motor were reviewed. Mathematical programming models used in resource optimization were also reviewed.

2.2 History of Rivatex East Africa Limited

Rivatex East Africa Limited is a Moi University facility for research, product development, extension and production. The Company is located about 1.5 kilometers from Eldoret town along the Eldoret, Kapsabet road. Rivatex East Africa Limited was incorporated in 1975 as a textile industry. It operated profitably until early 1990s when the textile market was liberalized. Due to high energy costs, the company faced stiff competition from textile imports. Its performance and profitability were severely affected leading to receivership in 1998 and eventual closure in 2000. Moi University acquired the institution in 2007 with the intention of turning it into training, research and manufacturing facility.

The facility includes offices, for both Rivatex East Africa Limited and Moi University, and an integrated textile mill that is fully equipped to handle the entire textile processing cycle from conversion of cotton to yarn through to woven fabric and finished fabric. The main products of the industry include yarn, woven fabric and finished fabric. Rivatex East Africa Limited products are sold locally and exported to international markets. The factory employs over 400 permanent and temporary staff. The main departments in the factory are spinning, weaving and wet processing.

2.3 Textile Manufacturing Processes

The textile industry has one of the most complex industrial chains in the manufacturing industry. Describing the textile manufacturing is complex due to wide variety of processes, machinery and components used, substrates and finishing steps undertaken. Fibers (yarns) production in spinning process, woven fabric production in weaving process and finishing processes (preparation, printing, dyeing, chemical/mechanical finishing, and coating), all interrelate in producing a finished fabric.

Although there are some integrated plants that have a number of steps such as spinning, weaving and finishing process all in one plant, a times all of these processes do not occur at a single facility. Spinning is the process of converting cotton or manmade fiber into yarn to be used for weaving and knitting. It involves blending, carding, combing, gilling, drawing, roving, spinning, winding, assembly winding, twisting and steaming.

Weaving is a process of textile production in which two distinct sets of yarns or threads are interlaced at right angles to form a woven fabric or cloth. The weaving process consists of several phases, such as: winding, warping, sizing, drawing-in, weaving and finally the control on the woven fabric. Finishing (wet-processing) refers to the processes that convert the woven or knitted cloth into a usable material. The general process sequence followed for the fabric wet processing involves: grey stitching, shearing and cropping, singeing, desizing, scouring, bleaching, mercerisation, dyeing and printing. Figure 2.1 is a generalized flow diagram displaying the various textile manufacturing processes that are involved in converting raw materials in to a finished product.

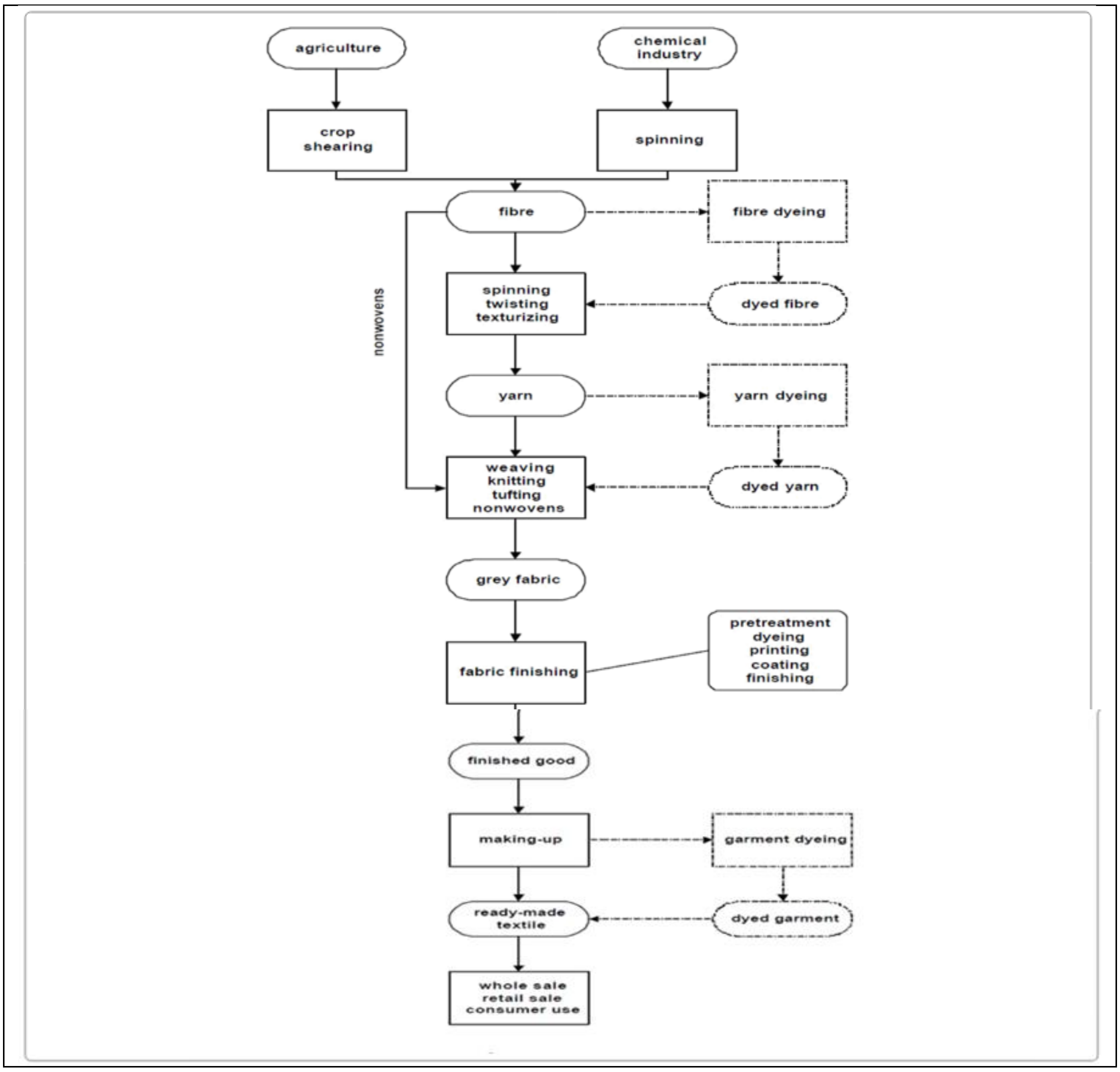


Figure 2.1: Textile Production Processes

(Source: Khude, 2017)

2.4 Energy Use in Textile Industry

The textile industry, in general, is not considered an energy intensive industry. However, the textile industry comprises a large number of plants which all together consume a significant amount of energy. The government of Kenya's Vision 2030 identifies the garment and textile sector as a driver of industrialization. Currently the sector contributes to 7 per cent of the country's export earnings. Kenya's manufacturing sector share of electricity consumption is approximately

50.2% while that of fuel consumption is about 12%, the second-highest after the transport sector, whose portion is 86.2% (Macharia, Gathiaka, & Ngui, 2022). Kenya has 52 textile mills, of which only 15 are currently operational and operate at less than 45 percent of total capacity with electricity as the major cost drivers of these firms (Karimbhai, Gebre, Joe, Tinga, & Biotechnology, 2022; Mangieri, 2019).

The share of total manufacturing energy consumed by the textile industry in a particular country depends upon the structure of the manufacturing sector in that country. For instance, the textile industry accounts for about 2% of the final energy use in manufacturing in Kenya. The share of the total product cost expended on energy in the textile industry also varies by country. Table 2.1 shows the energy cost ($/kWh) vs textile industry energy cost share from total production cost for different countries. Most research in textile industry from developed world, have found the energy cost to be around 5-10%, some Africa countries and Kenya (Rivatex East Africa) 15% - 25% and 27% respectively over the total production cost and it stands next to raw material cost. Hence now a day's area of focus is towards energy consumption at load end and by optimizing the efficiency of the motor, air compressor, boiler, lighting and steam distribution systems (Hasan et al., 2019).

Energy use performances and energy efficiencies of the industry have also been studied in different surveys in many countries (Vahabi Nejat, Avakh Darestani, Omidvari, Adibi, & Research, 2022). Research have been done by Pongiannan et al. (2022) in India on compressors and it was observed that there are energy losses in a compressed air system due to its ineffective conditions of equipment, operating parameters, and air leakage. Also, approximately half of energy used in textile industry is used to drive electrical motors. This means that efficiency improvements to electrical motors can have a very large impact on energy use. Motor-driven systems account for approximately 70% of the electricity used by Kenyan industries (e.g Rivatex East Africa, Eldoret). Further, the share of lighting in electricity use is relatively high and therefore, it is important to scrutinize whether the light source is utilized in the most efficient way and hence take the appropriate saving measures. By switching from tungsten bulbs to fluorescent lamps /energy saving bulbs and use of natural lighting, considerable electricity savings can be achieved.

Table 2.1: Electricity Price Cost Vs Textile Industry Energy Cost for different countries

S/NO	COUNTRY	U.S DOLLARS/KWH	ENERGY COST SHARE FROM TOTAL PRODUCTION COST
1	China	0.095	8%
2	India	0.106	12%
3	Korea	0.084	6%
4	Brazil	0.154	5%
5	Italy	0.349	10%
6	Turkey	0.116	9%
7	USA	0.128	6%
8	Vietnam	0.076	12%
16	Kenya	0.174	20-25%
17	Ethiopia	0.02	16.1%

Source: Author's compilation

Steam generation in boilers and distribution system is part of all the major processes involved in textile plant and therefore, the study to assess the overall performance of the steam system used in the textile or garment industry is critical. The quantity of heat loss through different sources both at steam generation and distribution unit will assist in coming up with the remedial measures such as optimization of the thermodynamic process parameters.

The real possibilities of a total efficient management of energy in the processes of the textile industry are made up of both real possibilities of modernization and optimization of processes as well as the complete replacement of the current machinery by new state-of-the-art technology (Cevallos & Ponce , 2022). But in this context, the investigation focuses on optimization of processes by studying the energy utilization and hence, proposing the saving opportunities in Kenyan textile industries. Bravo et al, (2022) studied the universal textile industry energy losses (see figure 2.2).

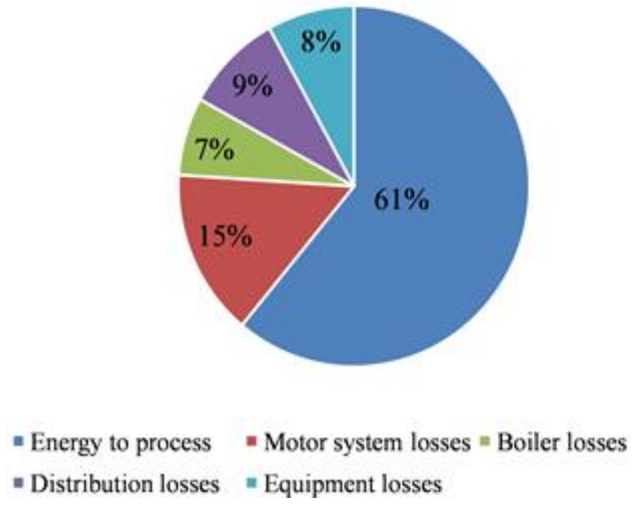


Figure 2.2: Textile industry energy losses on a universal scale
(Source: Bravo, Iturralde, & Management, 2022)

The savings and cost of the measures may vary depending on several factors, such as plant and process specific factors, type of fiber, yarn or fabric, quality of raw materials, specifications of the final product and raw materials (for example, fineness of the fiber or yarn, width or specific weight of the fabric g/m^2, etc.), the geographical location of the plant, etc. For example, for some of the energy efficiency measures, a significant part of the cost is the cost of labor; therefore, the cost of these measures in developed and developing countries can vary significantly (Jimenez-Marin et al., 2021).

Previous researches have been done on energy management in textiles industries. Qaisar, Khattak, Bilal, Imran, and Ulasyar (2021) studied electrical energy management in spinning area of textile industry and found substantial electrical losses and significant cost savings estimates which can lead to improved profitability and competitiveness. The electrical load in the spinning unit constituted about 60-65 % of the total electrical load in the whole industry consumption unit.

Cay, (2018) investigated equipment-wise energy use of textile production plants in Turkey and found that the steam production, compressors and lighting equipments have considerable share in total energy consumption and cost. The study found an average overall energy saving potential of 16.4%. Also application of energy efficient lighting equipment was found to have the highest energy saving potential corresponding to 63% of the total projected savings. In addition, study carried out in Taiwanese textile industries found energy saving equivalent to 94,614 MWh of electricity, 23,686 kl of fuel oil and 4,887 ton of fuel coal with the implementation of energy efficiency (Hong et al, 2010; Pattnaik & Dangayach, 2019).

Ozturk et al, (2020) studied the effect of priority energy efficiency techniques; process optimization, the establishment of a process-based energy monitoring and control system, the recovery of waste heat, the optimization of steam boilers, the modification of fan motors, the proper positioning of compressors, the installation of a compressor monitoring system on energy consumption. It was found that with the application of such techniques, electricity and thermal energy could be reduced by 8–27% and 12–28% respectively. Based on the financial analysis, the payback periods of the priority energy efficiency techniques were found to be generally less than 36 months.

Yalcın et al, (2020) carried out study on how to prevent unnecessary energy in the textile sector. As a result, the study found energy savings of up to 60% that can be saved by changing most machines and working methods used in the sector. Dewi et al, (2019) identified as much as 30% of energy saving potential would be achievable in Indonesia by 2025. Such amount of energy saving could be achieved through energy conservation and efficiency activity in many processes from fiber making to fabric finishing.

Tuigong and Kipkurgat (2015) studied on viability of using solar photovoltaic systems in textiles industries in Kenya, a case of Rivatex East Africa Limited in order to reduce the cost of production. The study found that for textiles industries to operate optimally and cut down on the production cost, there was need for alternative means of generating power and one of the options was to purchase and install solar PVC's.

Lin and Bai (2020) researched on the dynamic energy performance evaluation of Chinese textile industry using a global meta-frontier approach and found that the dynamic performance of the eastern region rises by 11.347%, while the central and western regions obtain a higher growth rate of 27.295% and 32.980% respectively.

Bravo et al, (2022) carried out an investigation on bibliographic review of the scientific contributions socialized by the Scopus database, and the information detected in the databases of the International Energy Agency (IEA) and International Renewable Energy Agency (IRENA) using an excel spreadsheets. The scientific contribution showed the ways in which efficient energy management influences the competitiveness of companies in the textile industry. Evidence on industrial energy efficiency in the textile industry in developing countries, particularly Kenya, is limited. The limited existing studies explore industrial energy efficiency in the whole country or analyze the implementation of energy saving measures.

2.4.1 Energy Use in a Composite Textile Plant

Electricity is the major type of energy used in spinning process, especially in cotton spinning systems. Energy is generally used for operating machines, air conditioning and illuminating the atmosphere where yarns are manufactured in spinning mills. In addition to these, compressors which provide compressed air to the spinning line use energy. Two types of energy can be used in a specific spinning mill; electrical energy and thermal energy. Machines, air conditioning, lamps used for illumination and compressors consume electrical energy while the thermal energy is consumed by air conditioning and processes such as fixation of yarns. Generally thermal energy is obtained from coal, diesel oil, fuel oil, natural gas and steam (Ozturk et al., 2020).

Two types of energy can be used in a specific weaving mill: electrical energy and thermal energy. Machines, air conditioning, lamps used for illumination and compressors consume electrical energy, while thermal energy is consumed by processes such as sizing and sometimes by air conditioning. Generally, thermal energy is obtained from coal, diesel oil, fuel oil, natural gas and steam (Dewi., et al, 2019).

Wet-processing is the major energy consumer in the textile industry because it uses a high amount of thermal energy in the forms of both steam and heat. The energy used in wet-processing depends on various factors such as the form of the product being processed (fiber, yarn, fabric, cloth), the machine type, the specific process type and the state of the final product. All wet and drying processes in the finishing department, together with the rewinding machines and quality control devices require electrical energy for driving the mechanical parts of the machines. At the same time, the washing of the grey fabrics, bleaching, dyeing, drying, post-treatment and fixation require a significant amount of hot air, hot water and steam. Therefore the consumption of electric energy in the finishing stage of the cotton fabrics is lower (53%), compared to the other production stages (Angelova., et al, 2021).

Studies show that for a composite textile plant that has spinning, weaving/knitting, and wet-processing (preparation, dyeing/printing, finishing) all on the same site, spinning consumes the highest amount of electricity (41%) followed by weaving (weaving preparation and weaving) (18%) and wet-processing (10%).

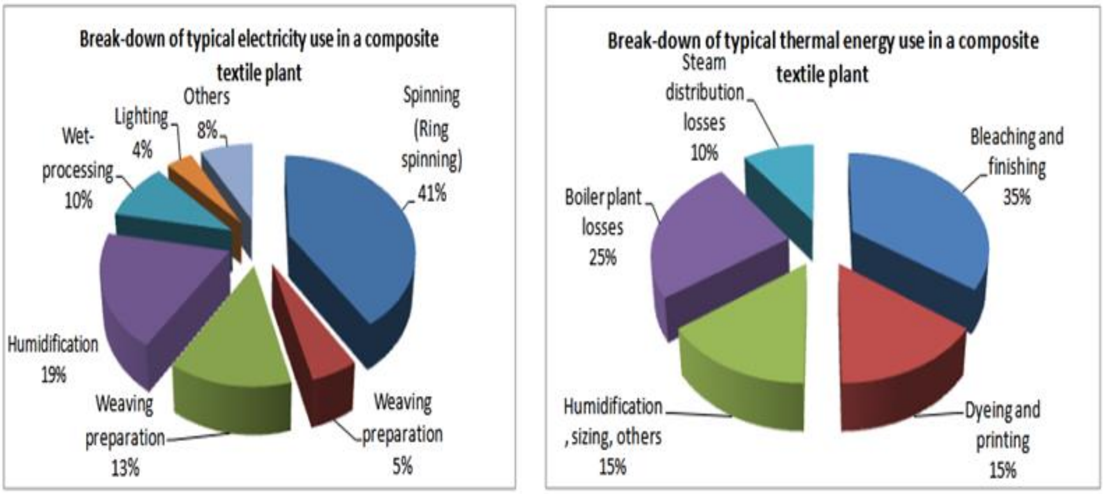


Figure 2.3: Breakdown of Typical Electricity and Thermal Energy Used in a Composite Textile Plant

(Source: Hasanbeigi & Price, 2012; Hasanbeigi & Price, 2015; Rajput et al, 2018).

Wet-processing preparation (desizing, bleaching, etc) and finishing together consume the highest amount of thermal energy (35%) as shown in figure 2.3. A significant amount of thermal energy is also lost during steam generation and distribution (35%).

2.4.2 Energy Use in Rivatex East Africa Ltd

Rivatex East Africa Ltd is a composite textile mill having spinning process, weaving process and wet-processing all in the same location. Electricity is used primarily for powering machinery, including air compressor, fans and shop floor lighting. In spinning process electricity is mainly used to power machines, such as carding and drawing machine to convert cotton into yarn. In weaving process electricity is used to operate weaving machines while firewood is used to provide steam needed in sizing process to strengthen the fibers while electricity and thermal energy are utilized in wet processing to power machines and provide steam for drying finished fabrics after dyeing. Thermo boiler is used to supply required heat in wet processing while wood fire-tube boiler is used to provide steam required in weaving process.

The industry keeps energy consumption records for electricity, firewood and oil against the daily productions for every department. On average the industry consumes 1,500,000 kWh annually of electricity representing approximately 70% of energy cost, 2,000 tones of wood fuel and 65,000 liters of furnace oil annually. The industry relies on two boilers and one air compressor which supplies air to the pneumatic machines in spinning. Proper storage of wood fuel is lacking and a times fresh wood fuel are used while air leakages are significant along the air piping system. The wood fire-tube boiler is poorly maintained and the wall casing is significantly damaged due to extensive corrosion on the surface.

The lighting system is dominated by T-12 fluorescent tubes which are used in all the departments though a number of them are dirty and some not working reducing illumination level. Also, large numbers of motors are used in the industry and some of them have been rewinded. In addition, the industry have extensive steam distribution which supplies steam from the boiler to weaving and wet-processing sections where it is used in sizing and dyeing respectively. The steam distribution system used is poorly maintained as most of the steam and heat pipes are not lagged while in others parts lagging material is deteriorated and steam leakages are significant.

2.5 Energy Efficiency and Energy Saving Opportunities in Textile Industry

There are various energy systems (cross-cutting" technologies) that can be found in almost all industrial plants such as motor systems, steam systems, compressed-air systems, boiler, and lighting systems. In addition, each industrial sub-sector has its own unique production technologies and processes. Energy-efficiency improvement opportunities can be found in both cross-cutting as well as industry-specific areas (Kissock & Eger, 2008). Energy saving measures can be short-term, medium-term and long-term measures according to the estimated payback period for the investment (Chew et al., 2015).

In order to lessen the amount of energy that is wasted, short-term solutions focus on modifying aspects such as the mentality of workers, their methods of production, the frequency of maintenance and control, as well as the procedures that are used for excellent housekeeping. These actions are typically simple to carry out and do not involve any form of investment; alternatively, they may call for a small investment but have a return period of less than a year. Measures that can be taken in the short term include optimizing boiler performance and steam distribution networks, making adjustments to equipment parameters such as column pressure and/or reflux ratio, and optimizing the operations of the compressor, refrigeration, and chiller systems.

In order to improve energy performance or promote heat recovery, medium-term interventions typically include making relatively minor adjustments to the plant installations or adjusting the processes that are already in place. These kinds of precautions call for an initial expenditure with a payback period of no more than three years. Projects such as utility or process heat recovery, retrofitting of heat recovery networks, installation of heat pumps, vapour recompression schemes, and high-efficiency equipment and motors are some examples of those that fall under this category.

Long-term remedies include considerable process heat recovery, combined heat and power generation, as well as moderate to major capacity expansion-related adjustments (cogeneration). Other feasible long-term initiatives include changing from batch to continuous operations, changing the linkages between process streams, automating the processing, and changing the technology used in processing. All of these changes involve a significant financial commitment. The required investment for this kind of modifications typically has a payback period that is longer than three years.

2.5.1 Energy Efficiency Improvement Opportunities in Electric Motors

Motors are used to drive mechanical devices and operation of other equipment such as air compressors, pumps, fans and conveyor belts (Ferreira & de Almeida, 2016). On average an industry may have hundreds of motors and their collective energy use can account approximately 70-80% of the total industrial energy consumption (Worrell, 2011). Studies show that adopting energy saving measures would result to energy savings of approximately 11-18% (Saidur, 2010). Energy saving opportunities on motors includes;

a) Maintenance

Maintenance on a motor has two primary purposes: to extend the life of the motor and to anticipate when the motor will break down. As a result, the methods of motor maintenance can be divided into two categories: preventative and predictive.

Preventative measures include reducing the amount of voltage imbalance, taking the load into consideration, aligning the motor, applying lubricant, and ventilating the motor. The goal of predictive motor maintenance is to monitor continuous motor temperature, vibration, and other operational data in order to determine whether and when a motor needs to be overhauled or replaced before it fails,(Barnish et al., 1997). The savings associated with an ongoing motor maintenance program could range from 2% to 30% of total motor system energy use (Saidur, 2010).

b) Energy-Efficient Motors

Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also stay cooler, may help reduce facility heating loads, and have higher service factors, longer bearing life, longer insulation life, and less vibration (Ferreira & de Almeida, 2016).

c) Rewinding of Motors

In some instances, it may be cost-effective to rewind an existing energy-efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (Hasanuzzaman et al., 2011).

d) Proper Motor Sizing

It is a persistent myth that oversized motors, particularly motors operating at less than 50 percent of their rated load, are inefficient and ought to be immediately replaced with appropriately sized energy-efficient units. This is especially true of motors that are operating at less than 25 percent of their rated load. In point of fact, there are a number of different pieces of information that are required to finish off an appropriate assessment of energy savings (Hasanbeigi & Price, 2012). The load that is being placed on the motor, the operational efficiency of the motor when it is at that particular load point, the full-load speed (measured in revolutions per minute, or rpm), of the motor that is going to be replaced, and the full-load speed of the downsized replacement motor are the four factors to take into consideration. When running at full load, the efficiency of both traditional and energy-efficient motors typically reaches its peak point somewhere around 75 percent, and it maintains a pretty steady level all the way down to the point where it is working at 50 percent. Motors in the bigger size ranges have the ability to run with a load as low as 25 percent of their rated load while still maintaining a reasonable level of efficiency. There are two more patterns: the first is that larger motors have greater efficiency values under full and partial loads, and the second is that the efficiency of smaller motors decreases more quickly after they are loaded below the point where they are at 50 percent capacity.

The vast majority of electric motors are built to operate at between fifty and one hundred percent of their rated load. Typically, maximum efficiency is reached somewhere around 75 percent of the rated load. When a motor is operating in a range where its efficiency reduces dramatically with decreasing load, such range is referred to as being under loaded. As may be seen in Figure 2.4, efficiency suffers a precipitous decline when loading levels fall.

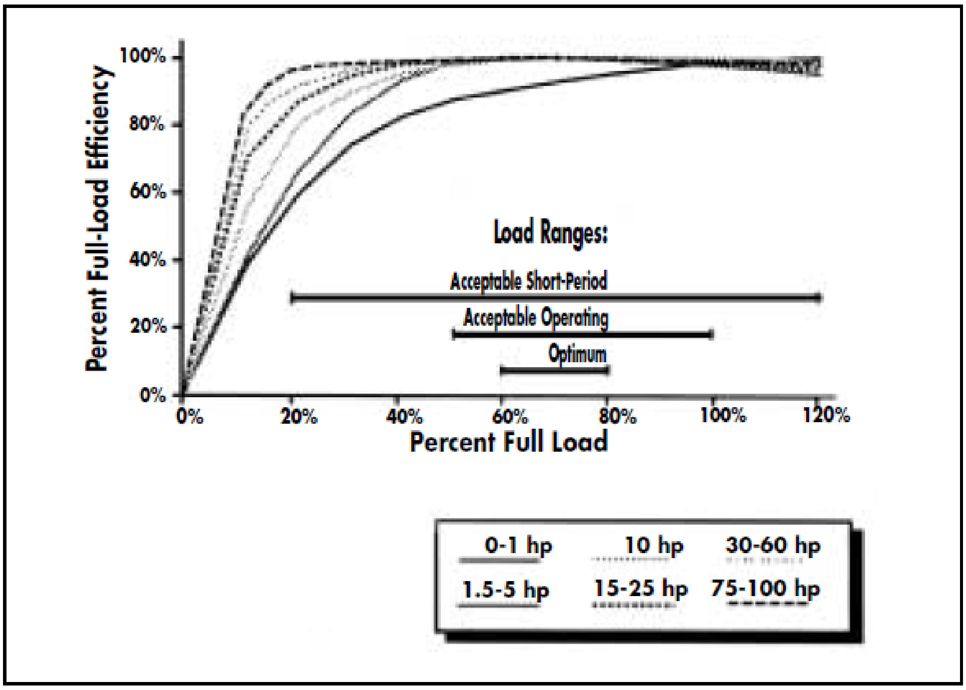


Figure 2.4: Motor part-load efficiency (as a function of % full-load efficiency) (Ferreira et al., 2016)

Over-sizing of electric motors is a common problem that varies from industry to industry, and from application to application (Saidur, 2010). In most cases, the lessons learned from experience indicate that the typical loads are only 65% of the motor's nominal power or the values that were specified for it. Because the motor is typically provided along with the apparatus, the user typically has no control over the amount of power that is output by the motor. The motors themselves are typically oversized because manufacturers of equipment take into consideration the most catastrophic outcomes that could occur during the course of normal equipment operation. Because of this, a motor that is grossly overgrown will have a power factor and efficiency that are worse than when it is operating under its nominal load. We can observe that the efficiency remains very constant and quite near to its maximum value up to around 75 percent of the full load, and that it drops by approximately 5 percent when the load is reduced to 50 percent. Efficiency drops considerably when loads are less than 50 percent of their capacity. The power factor is also negatively impacted when the load is reduced, which is a negative feedback loop. As may be seen in figure 2.5, the power factor decreases even more quickly than efficiency does. In light of this, the following outcomes can result from the over-sizing of electric motors: increase of investment costs for the motor itself; Increase of investment costs for accompanying equipment (switches, cables, etc.); increase of investment costs for capacitors for power factor correction and increase of electric energy costs due to lower efficiency.

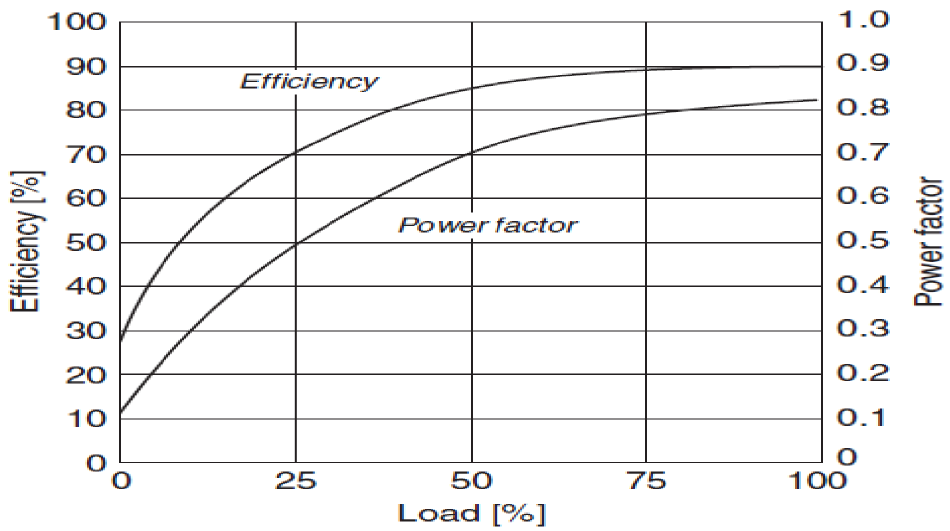


Figure 2.5: Efficiency and power factor to motor load relation
Source: Morvay and Gvozdenac (2008)

Percentage loading of the motor can be estimated by the following relation:

$$\%Loading = \frac{input\ power\ drawn\ by\ the\ motor(kw)at\ existing\ load}{nameplate\ full\ load\ KW\ rating/nameplate\ full\ load\ motor\ efficiency} \times 100$$

Or

$$\%\ loading = \frac{input\ power\ drawn\ by\ the\ motor\ (KW)at\ existing\ load}{\sqrt{3} \times kV \times I \times Cos\emptyset} \times 100$$

$$load = \frac{P_i}{P_{ir}} \times 100\%$$

Where:

Load = output power as a % of rated power

P_i = measured three-phase power in KW

P_{ir}= input power at full-rated load in KW

e) **Power Factor Correction**

The ratio of working power to perceived power is referred to as the power factor. It determines how efficiently the utilization of electrical power is being carried out. A high-power factor shows that the electrical power is being utilized effectively, while a low power factor suggests that the electrical power is not being utilized effectively. Transformers, electric motors, and HID lighting are all examples of inductive loads that have the potential to generate a low power factor. It is possible to improve the power factor by reducing the amount of time electric motors spend idling (a motor that is turned off does not use any energy), upgrading existing motors to ones that are more energy-efficient, and adding capacitors to the AC circuit in order to lower the total amount of reactive power produced by the system (Lotsu et al., 2019).

Capacitors connected in parallel (shunted) with the motor are typically used to improve the power factor. The impacts of PF correction include reduced kVA demand (and hence reduced utility demand charges), reduced I^2R losses in cables upstream of the capacitor (and hence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system (BEE; Lotsu et al., 2019; Shwedhi & Sultan, 2000).

The power factor of the motor is given as: $Power\ Factor = Cos\emptyset = \frac{KW}{KVA}$

2.5.2 Energy-Efficiency Improvement Opportunities in Compressed Air Systems

Compressed air system is one of the leading energy consuming equipment in industry. It is estimated that compressed air represents approximately 10% of industrial energy consumption (Bonfa et al., 2019). The total cost of compressed air over a ten-year period can be estimated as 75% energy, 15% capital and 10% maintenance. It shows clearly that energy efficient system is highly cost effective measure to reduce energy consumption (Morvay & Gvozdenac, 2008).

Because of this, inefficiencies in systems that use compressed air can be quite large. The amount of energy saved as a result of system enhancements can range anywhere from 20 to 50 percent or even more of the total amount of electricity consumed. If it is handled correctly, a compressed air system has the potential to save energy, cut down on maintenance costs, cut down on downtime, boost output, and improve product quality. Only 10–30 percent of the energy is utilized at the point of end-use, while the remaining 70–90 percent of the energy from the power of the prime mover is converted into heat energy that cannot be utilized, and some energy is also lost as a result of friction, improper use, and noise to a lesser extent. In manufacturing plants that use compressed air systems, the most significant source of wasted energy is typically found to be air leaks. Leakage can originate from any component of the system; however, the couplings, hoses, tubes, and fittings, pressure regulators, open condensate traps, and shut-off valves are the most frequently seen issue locations. Pipe thread sealants, disconnects, and joints are also available. In a properly maintained system, the amount of fluid lost due to leaks should make up less than 10 percent of the total. Twenty percent to fifty percent of a compressor's output can be lost due to leaks. The cost of compressed-air leaks is equal to the cost of the energy required to compress the volume of air that is lost, from the pressure of the surrounding atmosphere to the pressure at which the compressor is running. The cost of compressed air leaks rises proportionally with the diameter of the hole through which the air escapes. The amount of energy that is wasted in compressed-air systems due to improper installation and maintenance can account for up to fifty percent of the total amount of energy that is consumed by the compressor. It is believed that approximately fifty percent of this amount can be saved by engaging in practices that promote energy conservation, (Vyas et al., 2013)

Table 2.2: Typical specific power consumption of reciprocating compressors

Pressure bar	No. of stages	Specific power KW/170m^3/hr
1	1	6.29
2	1	9.64
3	1	13.04
4	2	14.57
7	2	18.34
8	2	19.16
10	2	21.74
15	2	26.22

Source: Dindorf (2012)

Many opportunities exist to reduce energy use of compressed air systems;

a) Reduction of Operating Pressure

Higher pressures increase leakage, and thereby the expenses. Usually, an increase of operating pressure is used to compensate for lack of capacity. The actual effect is quite opposite to the desired one. The higher pressure, higher is leakage, while the irregular consumers consume more air, and thus more energy. Each 1 bar of the pressure increase is followed by an increase in electrical energy consumption required to compress the air in a range between 5%and 8%, see table 2.2 (Blagojevic et al., 2020).

b) Maintenance

Inadequate maintenance can lower compression efficiency, increase air leakage or pressure variability and lead to increased operating temperatures, poor moisture control and excessive contamination. Better maintenance will reduce these problems and save energy.

c) Waste Heat Recovery

For screw air compressors there is a potential to use up to 50% to 90% of the heat which is drained off by cooling the air during compression. Waste heat recovery can be utilized economically up to approximately 30% of the total energy used for air compression. The heat energy generated can be used to raise boiler feed water temperature, industrial process heating and drying (Morvay & Gvozdenac, 2008). Recovering waste heat from air compressor for other industrial use offers 20% potential reduction in annual energy consumption (Radgen et al., 2001)

d) Reduction of Leaks (In Pipes and Equipment)

In an industrial compressed air system, leaks can sometimes squander 20-30 percent of a compressor's output, making them a substantial source of wasted energy. It is expected that a typical facility that has not been effectively maintained will have a leak rate that is equivalent to twenty percent of the facility's overall capacity to produce compressed air. Leak identification and repair can bring the amount of lost compressor production due to leaks down to less than 10 percent. According to several studies, plugging leaks in air compressors has the potential to cut annual energy use by twenty percent.

Leaks are not only a source of lost energy but can also contribute to other types of operational losses. A decrease in system pressure is caused by leaks, which can cause air tools to function less effectively, which in turn can have a negative impact on production, as well as shorten the life of system equipment, increase the amount of maintenance that is required, increase the amount of unscheduled downtime, and waste compressor capacity (Radgen and Blaustein, 2001).

e) Proper Pipe Sizing

Pipes must be sized correctly for optimal performance or resized to fit the compressor system. Inadequate pipe sizing can cause pressure losses, increase leaks and increase generating costs. Increasing pipe diameter typically reduces annual compressor energy consumption by 3% (Radgen & Blaustein, 2001).

2.5.3 Energy-Efficiency Improvement Opportunities in Boiler Systems

Boiler systems convert chemical energy of fuel to generate steam used in various industrial processes. The cost of boiler fuel is high due to its scarcity. The need to conserve environment and reduce air pollution demands use of high efficiency boiler systems to generate steam (Einstein et al., 2001). Energy efficiency measures available in boilers systems are;

a) Excess Air Control

The quantity of air that is given in addition to the amount of air that is required theoretically for complete combustion is referred to as excess air. In the event that the burner does not receive an adequate amount of air, unburned fuel, smoke, and carbon monoxide will be released into the flue gas. These factors may contribute to the formation of fouling on the surfaces that transmit heat, as well as to air pollution, inefficient combustion, and unstable operation of the combustion process. The amount of extra air is a critical factor that determines the effectiveness of the combustion process; hence, every effort should be made to supply the least amount of excess air that is practicable so that the combustion procedure can be both effective and efficient.

Table 2.3: Optimal flue gas composition

Fuel	O_2 (%)	CO_2 (%)	Excess Air (%)
Natural Gas	2.2	10.5	10
Liquid petroleum fuel	4.0	12.5	20
Coal	4.5	14.5	25
Wood	5.0	15.5	30

Source: El-Shafie et al. (2021)

Table 2.4: Theoretical combustion data – common boiler fuels

Fuel	Kg of air req./kg of fuel	Kg of flue gas/kg of fuel	m^3 of flue/kg of fuel	Theoretical CO_2 in dry flue gas	CO_2 in flu gas achieved in practice
Solid Fuels					
Bagasse	3.2	3.43	2.61	20.65	10–12
Coal	10.8	11.7	9.40	18.70	10-13
(bituminous)	8.4	9.10	6.97	19.40	9-13
Lignite	4.6	5.63	4.58	19.8	14-15
Paddy Husk	5.8	6.4	4.79	20.3	11-13
Wood					
Liquid Fuels					
Furnace Oil	13.90	14.30	11.50	15.0	9-14
LSHS	14.04	14.63	10.79	15.5	9-14

Source: Bhatia (2012)

The best surplus air level for achieving maximum boiler efficiency is achieved when the sum of the losses incurred as a result of incomplete combustion and the loss of heat owing to the flue gases is as low as possible. This can be evaluated by running tests with varying air fuel ratios. The optimal composition of flue gas, theoretical combustion data for different kinds of fuel, and typical values of extra air supplied to different kinds of fuel are provided in the following tables: 2.3, 2.4, and 2.5.

Table 2.5: Typical values of excess air supplied for various fuels

Fuel	Type of Furnace or Burners	Excess Air (% by wt)
Fuel oil	Oil burners, register type	15–20
Wood	Dutch over (10–23% through grates) and Hofft type	20–25

Source: (Bhatia, 2012)

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency (BEE).

b) Radiation and Convection Heat Loss

Normally the surface temperature of the boiler surface is higher than the surrounding. The degree of heat loss depends on the surface area of the boiler and difference between the boiler surface temperature and ambient temperature. Proper insulation of boiler reduces heat loss through boiler walls and piping. Radiation losses vary depending on the size and type of boiler;

(i) Fire tube	1.5 to 2.5%
(ii) Water tube boiler	2 to 3%
(iii) Power station boiler	0.4 to 1%

c) Reduction of Scaling and Soot Losses

Buildup of scales and soot on boiler tubes creates insulation which hinders heat transfer. High flue gas temperature is a clear indication of excessive scales and soot build up on the flue gas and water side of boiler tubes. Water treatment is necessary to minimize scales build up on the water side of the boiler tubes. It is estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5% due to increased flue gas temperatures. Regular cleaning of boiler tube surfaces and heat exchanger tubes is important to remove stubborn deposits (Barma et al., 2017).

d) Heat Recovery from Flue Gas

The temperature of flue gas leaving the boiler is normally high and ranges between 180- 300^{0}C. The boiler efficiency can be improved by tapping the flue gas exiting the boiler to increase the feed water temperature. The potential savings on the utilization of flue gas temperature to raise feed water temperature is estimated at 5%

improvement of boiler efficiency (Morvay & Gvozdenac, 2008). Flue gas temperatures should be as low as possible and temperatures greater than 200°C indicates potential for recovery of waste heat. It also indicates the scaling of heat transfer recovery equipment and hence the urgency of taking an early shut down for water and flue side cleaning.

2.5.4 Energy-Efficiency Improvement Opportunities in Lighting System

Lighting is used in factories and commercial facilities, both indoors and out, to make the working environment more pleasant. Complaints about poor lighting should be kept to a minimum, which can be accomplished by providing an adequate amount of illumination that is also properly balanced. This will ensure that working conditions are safe and productive. The major goal is to offer the needed standard levels of illumination while also minimizing the amount of power consumed.

Depending on the type of industry, the amount of electricity that is consumed by the industrial lighting might range anywhere between 2 and 10 percent of the overall power. The amount of light (illuminance) that must be present is mostly determined by the visible task at hand, the amount of time that is allocated to complete the task, the employee, and the relative relevance of the various task factors. The levels of illumination that are suggested for various tasks are outlined in Tables 2.6 and 2.7, (Uttam, 2015).

Table 2.6: Guide for recommended light level in different workspaces

Activity	**Illumination (lux,lumen/m^2)**
Public areas with dark surroundings	20-50
Simple orientation for short visits	50-100
Working areas where visual tasks are only occasionally performed	100-150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Table 2.7: Recommended illumination levels- Textile mills

Bale breaking, washing, Stock dyeing, tinting, Mixing, Blowing	200-300
Carding, drawing, roving	300-500
Spinning, doubling, reeling, winding	300-750
Warping	300-400
Sizing	400-500
Healding (drawing in)	750-1000
Weaving (plain gray fabrics)	200-300
Weaving (light coloured)	300-750
Weaving (dark coloured)	500-1000
Knitting	300-750
Dyeing	200-450
Calendaring, chemical treatment	300-750
Grey cloth inspection	700-1000
Final inspection	1000-2000

Energy saving opportunities in lighting includes;

a) Lighting Controls

Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors which turn off lights when a space becomes unoccupied. Manual controls can also be used in addition to automatic controls to save additional energy in smaller areas. The payback period for lighting control systems is generally less than 2 years (Galitsky et al., 2004).

b) Replace T-12 Tubes by T-8 Led Tubes

The initial output for T-12 lights is high, but energy consumption is also high. They also have extremely poor efficiency, lamp life, lumen depreciation and color rendering index thus increasing maintenance and energy costs. Replacing T-12 lamps with T-8 LED lamps approximately doubles the efficacy of the former, thereby saving energy consumption (Galitsky et al., 2004).

c) Optimum Use of Natural Sunlight

Many plants do not use natural sunlight to an optimum level. In addition to optimizing the size of the windows, transparent sheets can be installed at the roof in order to allow more sunlight to penetrate into the production area. This can reduce the need for lighting during the day.

2.5.5 Energy-Efficiency Improvement Opportunities in Steam Systems

Steam systems are often found in textile plants and can account for a significant amount of end-use energy consumption. Improving boiler efficiency and capturing excess heat can result in significant energy savings and improved production.

a) Insulation Improvement

Insulation can typically reduce energy losses by 90% and help ensure proper steam pressure at plant equipment (Therkelsen et al., 2014). The application of insulation can lead to significant energy cost savings with relatively short payback periods. For instance, the average payback period of the insulation on steam and hot water lines is 1.0 years, for condensate lines 1.1 year and that of the feed water tank 1.1 years (Einstein et al., 2001). The choice of insulating material depends on process temperature and its thermal conductivity. Table 2.8 provides thermal conductivity of various materials.

Table 2.8: Thermal conductivity of some insulating materials

Material	Density(kg/m^3)	Thermal conductivity(W/mK)		
		50^{0}C	100^{0}C	300^{0}C
Calcium silicate	210	0.055	0.058	0.083
Expanded nitrite Rubber	65-90	0.039		
Mineral wool(Glass)	16	0.047	0.065	
	48	0.035	0.044	
Mineral wool(Rock)	100	0.037	0.043	0.088
Magnesia	190	0.055	0.058	0.082
Polyisocyanurate foam	50	0.023	0.026	

Source: Morvay and Gvozdenac (2008)

b) Checking and Monitoring Steam Traps

A simple program of checking steam traps to ensure they operate properly can save significant amounts of energy. If the steam traps are not maintained for 3 to 5 years, 15-30% of the traps can be malfunctioning, thus allowing live steam to escape into the condensate return system. In systems with a regularly scheduled maintenance program, leaking traps should account for less than 5% of the trap population (Einstein et al., 2001). The repair and replacement of steam traps has an average payback time of 0.4 years (U.S. DOE-IAC, 2006). Energy savings for a regular system of steam trap checks and follow-up maintenance is estimated to be up to 10% (Barma et al., 2017).

c) Reduction of Distribution Pipe Leaks

As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. On average leak repair has a payback period of 0.4 years (Barma et al., 2017).

2.6 Energy Optimization Models in Textile Industry

Textile industries need to allocate and use available energy resources at their optimum level without affecting the quality of products so as to remain competitive both in local and global markets. Mathematical models play an important role in providing solutions to energy optimization problems. For this research, linear programming model has been developed to optimize the energy utilization in the textile manufacturing plant.

Previous research shows that the Goal programming model have been employed in energy optimization to resolve production scheduling problem by providing a solution that meets three meta-goals. The three meta-goals are minimizing the sum of undesired relative deviations, minimizing the maximum relative deviation from a set of targets and minimizing the range of unachieved goals. The study found an optimum solution that met all three meta-goals, with some original goals being partially met (Malik & Roy, 2022). Also goal programming was used to solve production planning in the drying sector of an industrial laundry by minimizing energy and labor costs and to use full capacity of each piece of equipment, as far as possible. The study demonstrated that it was possible to establish plans for efficient production and optimal allocation of resources (Oliveira et al., 2017).

Furthermore, a fuzzy meta-goal programming model was used in a textile manufacturing plant in India where the objective was to determine the number of units to be produced and hence sold within the given restrictions. Three types of meta-goals were considered which were assumed to have fuzzy bounds to manipulate the degree of attainment for the prioritized goals. The study found that the decision-maker can establish target values not only for goals but also for relevant achievement functions (Bhargava et al., 2015). In addition, optimization of the master production scheduling in a textile industry was done using Genetic Algorithm. The study found that with the use of genetic algorithms, the MPS is optimized to carry out production planning, with an improvement of up to 96% of the level of service provided (Lorente-Leyva et al., 2019). Genetic algorithm was used in Indonesian textile factory to find minimum total makespan (the total processing time from the first item enters the production line until the last item leaves the production line in the same batch that is considered to be too high). The results was tested and proven to be reliable in generating production schedules with lower makespan compared to existing scheduling process in the same factory (Kurniawan et al., 2014).

In addition, Linear Programming model (LP) has been extensively used in textile industry energy optimizations. LP model was used in a research done in Rozha Textiles Ltd in Bangladesh to maximize profits. The objective function was to maximize profit while Labor cost, machine cost and other cost were considered as subject to constraints. The results showed that that fabric cost and machine cost are the most sensitive cost. If the fabric cost and machine cost can be decreased, the profit will also increase (Nisita, 2021; Harianto et al., 2018; Eshetie et al., 2016). Likewise LP model has also been used in identifying product mix of textile products to maximize profit and cost optimization. The results displayed a 54% increase post LP compared to the product-wise resource utilization. Similarly, the profit using Linear programming was more than double as wastage and costing were minimum, and revenue was high (Chanda et al., 2022; Harianto & Sari, 2022). Moussa, (2021) applied LP model to solve the textile color formulation problem by finding the appropriate dyes to mix and their exact concentrations, which, when applied correctly, produce the required color. The findings showed very good results with very small values of errors and color differences. Workie et al., (2016) used LP model to determine the type and quantity of textile dyed fabrics. The LP model provide faster decision on the type and amount of textile dyed fabrics to be produced that yield more income than strategies obtained from trial and error methods to be improved by 72.63% and 65.91%. Dragicevic & Bojic, (2009) used LP model in determining optimum values for the process design variables for energy in steam condensing systems (decreasing operating costs of the energy system that consisted of the boiler, the desuperheater, the turbine with steam extraction, and the heat pump). Results of optimization showed that maximum costs saving is up to 88 % for the system with condensing turbine without steam extraction and up to 60 % in the system with turbine with steam extraction. Amirthalingam, (2021) research on scheduling carried out in a garment industry in textile city Karur, India used LP model on workers scheduling.

Moreover, study in Malaysia applied fuzzy linear programming model to solve Production Planning problem in the Textile Industry. The study found that the recursive iteration method used is an efficient and effective way to solve fuzzy problem of production planning in the textile industry (Elamvazuthi et al., 2010). A case study done in an apparel industrial unit based in Mumbai, Maharashtra, India used linear programming model to determine optimal product mix with the aim of making maximum profit. The study found that the company should produce 200 skirts, 45 tops, 200 dresses and 100 pants per day (Akshar et al., 2019). Research on resource utilization in Ethiopia textile industries applied linear programming model to enhance resource utilization. The findings of the study depicts that all of the organizational resources were severely underutilized and displayed that the resource utilization of the case company can be improved from 46.41% of the current resource utilization to 98.57% (Tesfaye et al., 2016).

Research carried out in Turkey textile industry, used fuzzy linear programming model to solve production planning problem by determining the production amounts in the Industry. The model provided the solution by giving the amount of production for each cloth type in order to gain maximum profit (Teke et al., 2017). Campo et al., (2018) used linear programming model to solve aggregate production planning in a textile company by minimizing total costs associated with labour and inventory levels. Shakirullah et al., (2020) used linear programming model in profit optimization of an apparel industry in Bangladesh. The study revealed that the profit of the case company can be increased by 22% when there is sufficient demand and that can be 12.33% when clients' requests are to be met. On the other hand, cost may be decreased by 37% by using the LP model. Woubante, (2017) used linear programming model to solve optimization problem of product mix. According to the study's findings, if customer orders are to be fulfilled, the company's profit can be boosted by 59.84%, or from Birr 465,456 per month to Birr 777,877.3 per month, by using linear programming models. If customer orders are not taken into account in the linear programming formulation, the company's profit can increase by 7.22%.

In conclusion, research on production-related topics has typically placed a strong emphasis on maximizing profit, product mix, staffing and lowering labor cost. As a result, essentially no research has been done on the textile production industry that addresses attaining goals like reducing energy costs and satisfying customer needs without compromising product quality. The study's goal is to create an energy model that would optimize the use of energy in textile manufacturing industry. It is suggested that the LP technique is a more adaptable approach because a final solution may be found in a single computer run, negating the need for several solutions that the case study approach calls for. It is best to analyze complex industrial systems using linear programming since it minimizes or maximizes an objective function of many independent variables. The energy cost in the textile industry is used to illustrate how mathematically sound and practical the suggested technique is in this sector. To the best of our knowledge, this study may be the first to offer an LP model specifically designed for the textile manufacturing sector, which will help managers make decisions that concurrently meet many goals.

2.7 Research Gap

Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy efficiency should be one of the main concerns of textile plants. There are various energy-efficiency opportunities in textile plants, many of which are cost-effective. However, even cost-effective options often are not implemented in textile plants due mainly to limited information on how to implement energy-efficiency measures, especially given the fact that the majority of textile plants are categorized as SMEs. Know-how regarding energy efficiency technologies and saving opportunities should, therefore, be prepared and disseminated to textile industry.

This study seeks to address the research gap by providing evidence on how to reduce the energy costs in Kenya's textile industry sector. The study is based on the optimization of energy utilization using linear programming model and proposing the saving opportunities. Unlike previous studies, this study provides separate evidence for energy utility systems and equipment.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the data collection method, research tools, performance evaluation methodologies, experimental procedures and mathematical model employed in energy optimization.

3.2 Data Collection

Standard measurement techniques stipulated in the energy efficiency assessment manual by Association of Energy Engineers (AEE) were adopted to investigate the energy utilization in the plant. Data on the plant's historical energy consumption and production over the course of two years for the spinning process, weaving process and wet processing were collected from current records of case study industry for the purpose of evaluating the qualities of the energy systems and the patterns of energy use for the plant. In order to better illustrate the monthly trend as well as the relationship between energy use and production, both pie charts and line graphs were generated for the years 2016 and 2017. Then primary data were collected from on-site measurement.

The unit cost of various energy inputs was determined from utility bills for the past two years as a reference. Additionally, the periods of operation as well as the annual plant and equipment running hours were recorded. Specific energy consumption for yarn (Kwh/kg), woven fabric (Kwh/kg) and finished fabric (Kwh/kg) were determined using the following formula (Hasanbeigi and Price, 2010);

$$Specific\ Energy\ Consumption(SEC) = \frac{Energy\ Consumption(E)}{Production(P)} \tag{3.1}$$

Statistical analysis was done to determine the relationship between dependent variable and independent variable. For this research energy consumption is dependent variable and production an independent variable (Morvay & Gvozdenac, 2008).

3.3 Research Instruments

Portable instruments were used to determine the efficiency of boilers, motors, lighting systems, air compressor and steam distribution system. The following instruments were used in this research; flue gas analyser-testo 310 was used to measure O_2, CO_2 and CO in ppm and temperature in flue gas of boilers. Power and energy logger-pel 103 was used to measure, record real time power consumption, voltage, current, PF, analysis of electrical load, demand control, harmonics and transient. It was done without interrupting the connections. Lux meter was used to measure illumination level of lighting systems. Clamp meter was used to measurement of current without interrupting the connections while infrared thermometer was used to measure temperature from a distance for steam pipes and boiler surfaces**.**

3.4 Performance Evaluation Methods and Experimental Procedure

High energy intensive utility systems and equipments were chosen for energy efficiency evaluation. Performance efficiency for all the two boilers and one air compressor owned by the company was done while sampling was done randomly to determine the efficiency of motors, lighting and steam distribution systems.

3.4.1 Compressed Air System

The industry owns a rotary screw air compressor (GA-808, Atlas Copco) used to operate pneumatic machines in the textile plant. The air compressor serves spinning, weaving and wet processing departments for 16 hours a day. The design specifications of GA-808 air compressor are follows; maximum pressure (8 bar), absolute intake pressure (1.017 bar), free air delivery (183 l/s), motor power (75 kw) and maximum speed (1,500 r/min).

The power consumption of air compressor was measured with power and energy logger. The setup of the experiment inside the compressor control panel is shown in the figure 3.1. The measured parameters include; voltage, current, PF, kW, kVA and kVAR.

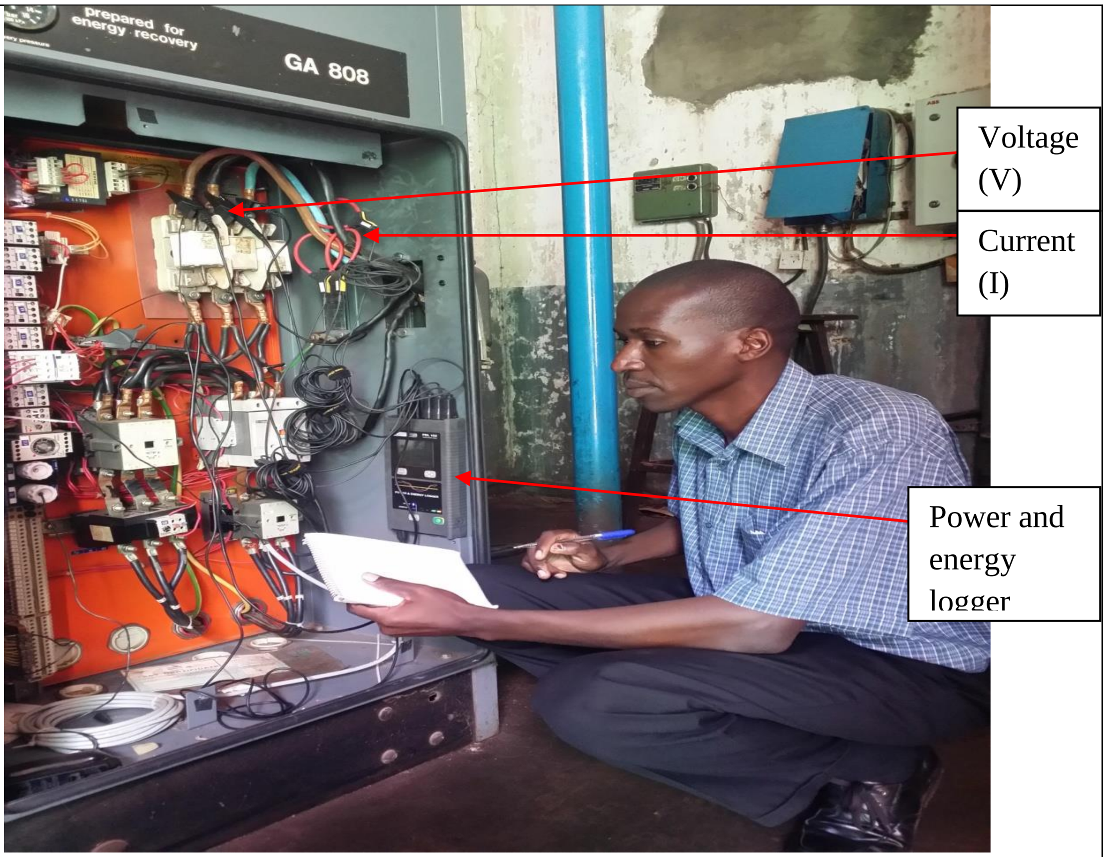


Figure 3.1: Power and energy logger set up for Air compressor energy consumption trends recording

An air leak test was carried out while the air compressor was turned off in order to ascertain the level of the percentage of air that was lost. The procedure required turning on the air compressor after ensuring that all end-use equipment that utilized air had been switched off. The experiment was conducted three times to determine the average time it takes to load and unload the compressor. Total air leak was determined according to Morvay & Gvozdenac, 2008.

$$Leakage(\%) = \frac{T \times 100}{T+t} \quad (3.2)$$

Where:

T = on-load time

t = off-load time

$$System\ leakage(L/s) = \frac{Q \times T}{T+t} \quad (3.3)$$

Where:

Q = compressed air capacity (Liters)

$$Energy\ loss(kWh) = H \times P[\frac{T}{T+t}] \quad (3.4)$$

H = Annual working time for the factory in hours

P = Compressor rating (kW)

Total cost for energy loss = energy loss (kWh) × KES/kWh (3.5)

3.4.2 Lighting System

Total number of luminaires (N) required to provide recommended level of illumination (E) at a given surface is given by equation 3.6 (Tong et al., 2022);

$$N = \frac{E \times A}{n \times F \times UF \times MF} \quad (3.6)$$

Where,

N = number of luminaires

E = the illuminance level (lux/m^2)

A= the working area to be illuminated (m^2)

n = number of lamps per luminaire

F= lamp luminous flux (lumens)

MF = maintenance factor (0.8 -0.9).

UF = Utilization Factor (0.9)

Annual energy savings was calculated on replacement of existing T-12 fluorescent tube with energy saving T-8 LED tubes. The formula used to calculate energy savings is as follows:

$$Total\ Power\ rating(TP) = LR \times NL \tag{3.7}$$

Where:

LR = Lamp rating

NL = Number of lamps

$$Annual\ energy\ consumption(AEC) = TP \times OH \tag{3.8}$$

Where:

OH = Operating hours

$$Annual\ energy\ savings(AES) = AEC_{old} - AEC_{new} \tag{3.9}$$

Where,

AEC – Annual energy consumption

$$Annual\ saving\ cost\ (ASC) = AES \times Ksh/kWh \tag{3.10}$$

3.4.3 Boiler System

The boilers utilized in the industry are wood fire-tube boiler and thermo boiler as shown in Figure 3.2. Wood fire-tube boiler uses wood as fuel while thermo boiler uses furnace oil. The steam generated by wood boiler is used in the treatment of yarns to improve strength while thermo boiler provides heat used in the treatment of woven fabric after dying.

Figure 3.2: (a) Wood fire tube boiler and (b) Thermo boiler used in Rivatex East Africa Ltd

Flue gas analysis was carried out in order to get data necessary in the calculation of the combustion and heat utilization efficiencies as well as to evaluate the operation of the boiler. The indirect method was used to calculate the performance efficiency of the boilers (heat loss method). The efficiency by heat loss method can be calculated as the difference between the energy lost and the energy put in. The efficiency of the boiler was determined by deducting the percentage of heat lost from 100. The following are the primary heat losses that were determined;

L1- Loss due to dry flue gas

L2- Heat loss due to evaporation of water formed due to H_2 in fuel

L3- Heat loss due to moisture present in fuel

L4- Heat loss due to moisture present in air

L5- Heat loss due to incomplete combustion

L6- Heat loss due to radiation and other unaccounted losses

L7- Heat loss due to unburnt in bottom ash

L8- Heat loss due to unburnt in fly ash

Boiler Efficiency by Indirect Method =100 – $\sum_{i=1}^{8} L$)

Boiler Efficiency, η= 100 - (Total Loss in %)

To determine the efficiency, measurements were made at an interval of 5 minutes for three times at the boiler end. In order to determine the composition and temperature of the combustion gas, portable flue gas analyzer was used as shown in figure 3.3 and 3.4. The measurement was based on combustion gas composition, excess air and the temperature of the combustion gases out of the installation.

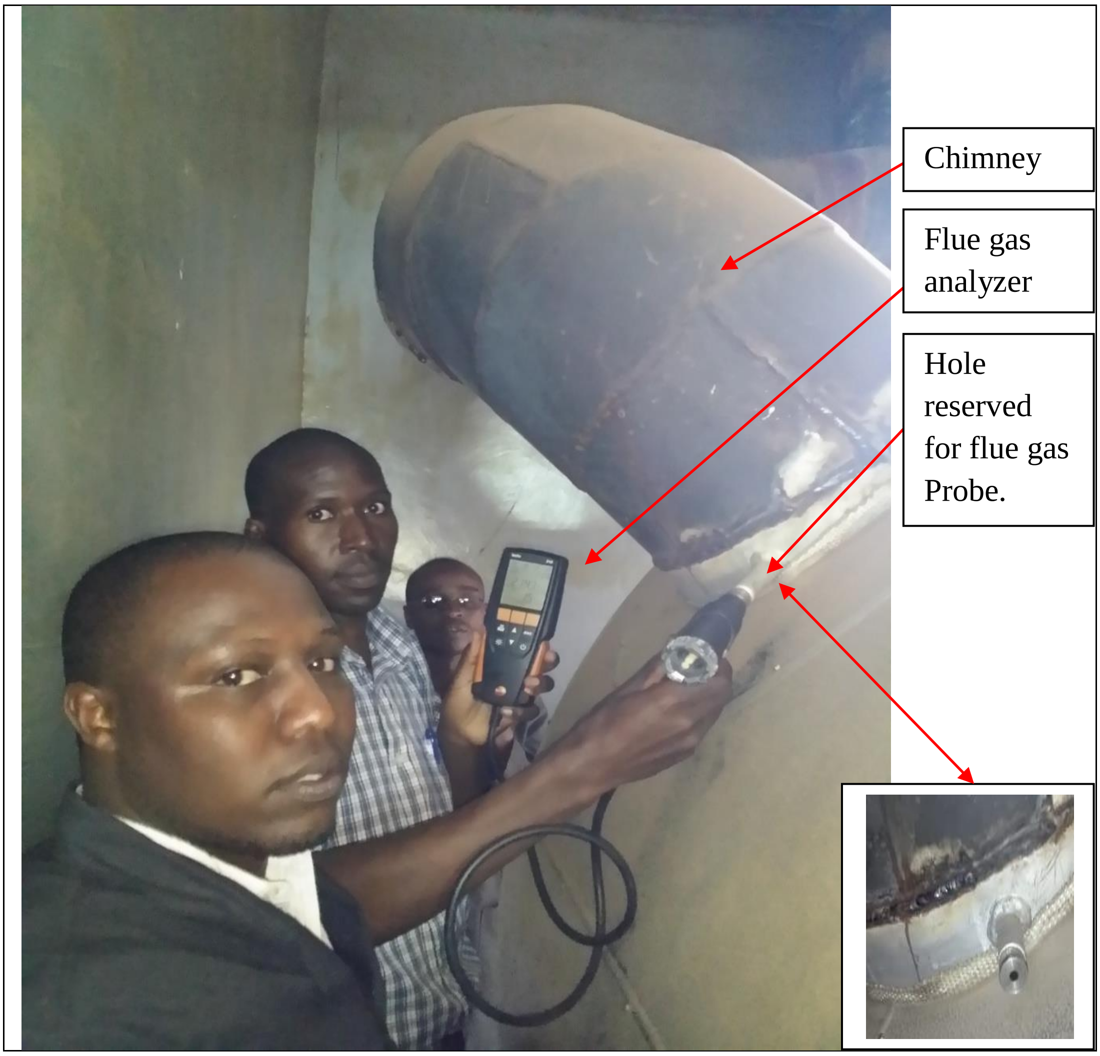


Figure 3.3: Flue gas sampling using flue gas analyzer

Parameters collected for boiler efficiency calculation were; Percentage of Oxygen in the flue gas, Percentage CO_2 in the flue gas, Percentage CO in the flue gas, Flue gas temperature in °C (T_f), Ambient temperature in °C (T_a), Humidity of air in kg/kg of dry air, GCV of fuel in kCal/kg, Percentage combustible in ash, GCV of ash in kCal/kg, (1kcal/kg = 4.1868 KJ/kg)

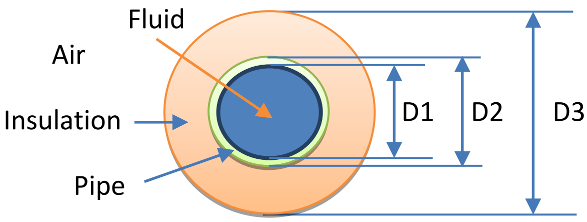
Figure 3.4: A typical display of flue gas temperature and oxygen readings on flue gas analyzer

3.4.4 Steam Distribution System

The setup of the industry requires extensive use of steam distribution pipes to transport steam to different point of use as shown in figure 3.5. The widespread steam locations attract steam losses due to heat radiation and pressure drops.

The heat loss on bare mild steel pipes was determined by measuring the diameter and length of pipe using tape measure. Ambient and fluid temperature was measured using infrared thermometer. The heat loss through the wall of pipe per unit length was calculated as follows (Fourier’s law);

Figure 3.5: Bare (uninsulated) heat distribution systems



$$Q = \frac{2\pi k(t_1 - t_2)}{ln\left(\frac{r_2}{r_1}\right)} \quad \text{(W/m)} \qquad (3.11)$$

Where,

Q= heat loss per meter

k= thermal conductivity of pipe wall (W/mK)

t_1= internal temperature

t_2= external temperature

r_1= internal radius of pipe (m)

r_2= external radius of pipe (m)

The thermal resistance per unit length of pipe was calculated as follows,

$$R = \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi k} \quad \text{(mk/W)} \tag{3.12}$$

The flow of hot fluid through the pipe causes transfer of heat to the pipe wall. The thin stationary layer of fluid on the pipe wall determines the rate of heat transfer. The rate of heat transfers across the thin stationary layer was determined as follows (Newton's law of cooling),

$$Q = h \times A \times (T - t) \tag{3.13}$$

Where,

h= heat transfer coefficient (W/m^{2}K)

A= surface area (m^2)

$T - t$= temperature difference between the surface and the fluid (^{0}C)

The above equation can be used to determine the heat transfer across the external surface of pipe. The internal and external surface resistance per unit length of pipe is expressed as follows,

$$\mathrm{R_i} = \frac{1}{\mathrm{h_i} \times \mathrm{A}} \tag{3.14}$$

$$\mathrm{R_o} = \frac{1}{\mathrm{h_o} \times \mathrm{A}} \tag{3.15}$$

Overall resistance per unit length of insulated pipe is expressed as:

$$R_t = R_i + R_o + R_p + R_{ins} \tag{3.16}$$

Where,

$R_{t=}$ overall thermal resistance of pipe per unit length (mK/W)

$R_{i=}$ internal thermal surface resistance of insulation per unit length (mK/W)

$R_{o=}$ external thermal surface resistance of insulation per unit length (mK/W)

$R_{p=}$ thermal resistance of pipe wall per unit length (mK/W)

$R_{ins=}$ thermal resistance of insulation material per unit length (mK/W)

Once the overall thermal resistance per unit length is determined, then the heat loss per meter was calculated as follows;

$$Q = \frac{T-t}{R_t} \text{(W/m)} \tag{3.17}$$

Or

$$Q = \frac{2\pi L(T-t)}{\frac{1}{h_i r_1}+\frac{\ln\left(\frac{r_2}{r_1}\right)}{K_p}+\frac{ln\left(\frac{r_3}{r_2}\right)}{K_{ins}}+\frac{1}{h_o r_3}} \quad \text{(W/m)} \tag{3.18}$$

Where,

T= temperature of the fluid

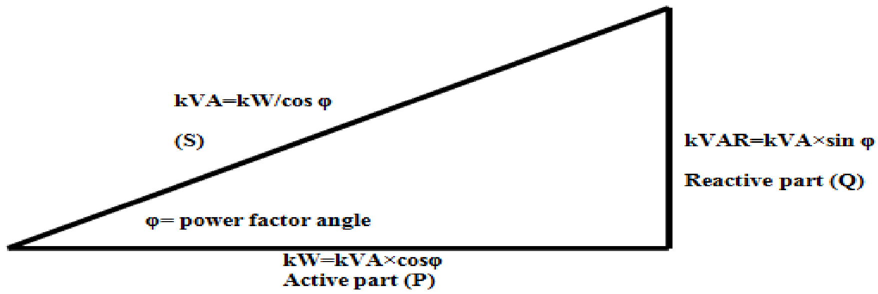
t= ambient temperature

R_t= total resistance

3.4.5 Motor System

The manufacturing industry relies on a significant quantity of motors to power its assortment of machines. The most significant consumers of energy in a factory are the motors. It is routine practice to rewind motors, and a representative sample of 10 motors was chosen for analysis to calculate the power factor and compare it to the characteristics listed on the nameplate. As part of the performance measuring process, a power and energy logger instrument were utilized.

The total power requirement of a load is made up of these two components, namely the active part and the reactive part as shown in the diagram.



$Power = \sqrt{3} \times V \times I \times cos\varphi$

Where $cos\varphi$= power factor

$$PF = \frac{P}{S} = cos\varphi$$

$$Load\ factor = \frac{average\ load}{maximum\ load} \times 100$$

Apparent power is given by $S = \frac{P}{cos\varphi}$ (3.19)

3.5 Mathematical Model

In this research, a linear programming model was utilized to provide a solution for the energy problem. Linear programming solves problems by minimizing or maximizing a function of several independent variables and best for analyzing complex industrial systems. The LP technique is more flexible method and a final solution is obtained in a single computer run thus eliminating the numerous solutions required by the case study approach.

The simplex algorithm was used to calculate the optimal allocation of resources for each of the three manufacturing processes for textiles, with the goal of producing the entire monthly product demand at the lowest possible cost in terms of energy consumption. A linear goal function and one or more linearly formatted constraints are what constitute this paradigm. The purpose of the linear programming (LP) problem, as represented by its mathematical representation, is to maximize (or minimize) the value of the objective function.

$$Maximize\ or\ Minimize\ \ Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n \qquad (3.20)$$

Subject to n constraints

$AX \leq b,\ X \geq 0$

The values in the X vector are called decision variables (the unknowns), and the values in the b vector are often called right-hand sides (RHS).

Linear Program Solver (LiPS v1.11.1 software.) was used to solve the energy problem in this thesis. Linear Program Solver (LiPS) is an optimization package oriented on solving linear, integer and goal programming problems. It takes the optimization equation, variables and constraints as the input and generates the optimum solution as the output. The input data for the model were energy (electricity, wood fuel and oil fuel) used per unit of each product at each stage.

3.6 Limitations and Assumptions

This study faced challenges in obtaining relevant historical data. Energy consumption and production data for case study industry were not organized. The fact that the relevant data was scattered, and was not available in company databases, the researcher had to collect, reorganize and evaluate archived companywide documents. To meet the study objective both secondary and primary data were collected, analyzed and interpreted.

Due to high cost of investigative energy instruments, sampling of motors was done. It was assumed that the performance of sampled motors give representation of other motors used in the industry. Also, though sampling of flue gas was done three times, the flue gas test was done only in one day and assumed to be sufficient to determine efficiency of the boilers.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the outcomes of the study are presented. To start with energy utilization in Rivatex East Africa Ltd, energy consumption pattern, specific energy intensity and statistical analysis for spinning, weaving and wet processing are presented. Also, performance evaluation of energy efficiency, as well as energy saving and conservation measures for various energy utility systems and equipment, such as motors, boilers, air compressors, lighting, and distribution systems are given.

4.2 Energy Utilization in Rivatex East Africa Ltd

Electricity, wood fuel, and furnace oil are the primary types of energy that are put to use at Rivatex East Africa Ltd. Electricity is mostly utilized in the operation of motors and lighting, whereas furnace oil and wood fuel are predominantly utilized in the processing of yarn and woven cloth. Kenya power, at the C13 tariff, supplies the sector with energy at 33 kilovolts, which is then transformed into 11 kilovolts using four step-down transformers. Transformer 1- supplies power to spinning monitored by B_1 meter, Transformer 2- supplies power to preparation/weaving monitored by B3meter, Transformer 3- supplies power to wet processing monitored by B4 meter, Transformer 4- supplies power to the boiler monitored by B0 meter

The breakdown of energy utilization at Rivatex East Africa Ltd for the year 2016 and 2017 are presented in figure 4.1 and figure 4.2.

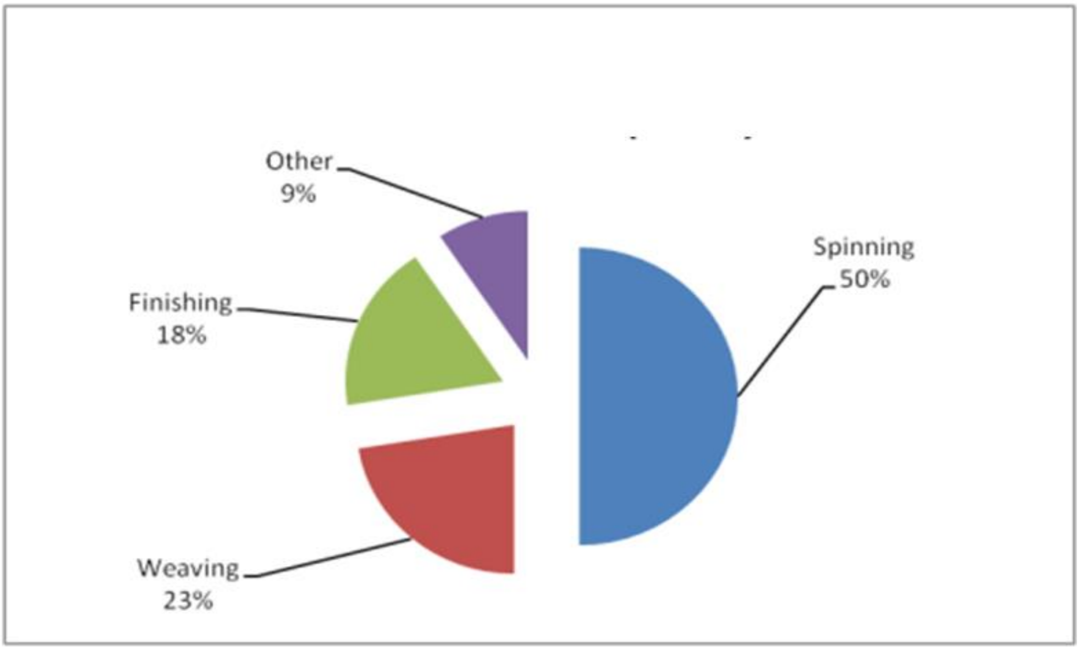


Figure 4.1: Breakdown of Electricity consumption (2016)

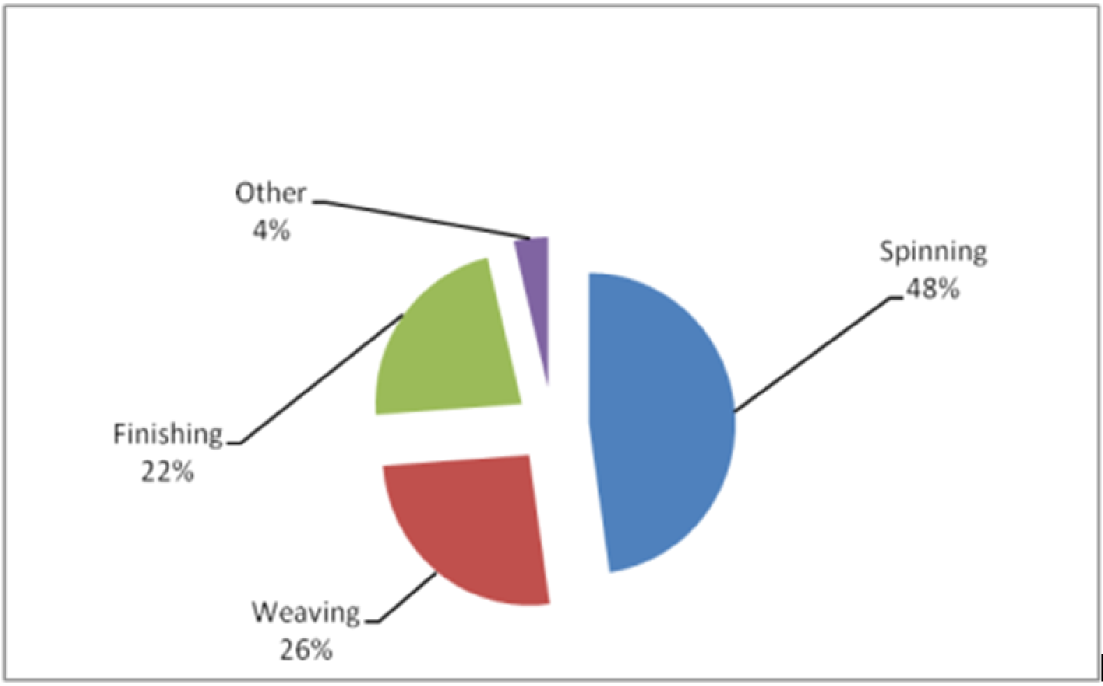


Figure 4.2: Breakdown of Electricity consumption (2017)

It was observed from figure 4.1 and 4.2 that for the two years studied, high amount of electricity is consumed in spinning process followed by weaving process and lastly wet processing of the case study plant. This is attributed to the fact that most of the stand alone machines such as blending, carding, combing, gilling, drawing, roving, spinning, winding, assembly winding and twisting machines are powered by high rated motors. Also, the processes required to transform raw material to yarn to be used in weaving is extensive and all machines are entirely driven by electric energy. Weaving process was found to consume approximately 50% of energy consumed in spinning process in the plant. This is due to the fact that weaving process involves winding, warping and sizing which rely on electricity but the process involved is not as extensive as for spinning process. In addition, weaving process relies on both electric energy and thermal energy. Further, since weaving process machines are compact they are powered by low rated motors which consume less energy compared to spinning process machines. The amount of electricity consumed in wet processing was found to be low compared to the other two processes due to the fact that preparation stages rely heavily on thermal energy. In addition, the machines powered by electricity are not as many compared to spinning and at the same time not energy intensive.

Though the results were found to be in line with other studies (Sathaye et al., 2005) in textile manufacturing, it was observed that energy consumed was higher compared to that of developed countries. This implies that energy consumption in the case study industry could be minimized by improving energy efficiency of utility systems and equipment such as motors and air compressors.

4.3 Energy Consumption Analysis for Spinning Process

4.3.1 Energy Consumption Pattern for Spinning

Figure 4.3 shows two years' historical energy consumption and production data for spinning process.

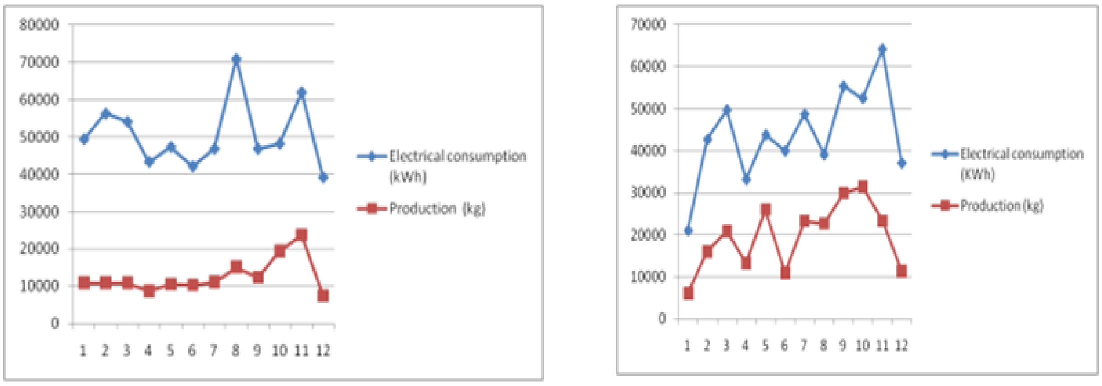


Figure 4.3: Historical monthly production and electricity consumption pattern for spinning process for the year 2016 and 2017

It was observed from figure 4.3 that though production change in 2016 was minimal, energy consumption fluctuated for the period. This is attributed to inefficient spinning machines (drawing machine) which consumed more power with little production. High consumption of electricity in the month of August 2016, could be attributed to breakdown of inefficient carding and drawing machine used in spinning which were later replaced .Outdated machines consume more electric energy due to diminished efficiency hence low production. The pattern for energy consumption and production for year 2017 was consistent almost throughout the period due to the fact that inefficient spinning machines were replaced. Modern well maintained machines consume minimal energy while attaining high production and quality levels.

4.3.2 Specific Energy Intensity for Spinning Process

It was observed from figure 4.4 that specific energy intensity for year 2016 was higher than that of year 2017 due to the fact that inefficient drawing frame machine was replaced. Although the specific energy intensity for year 2017 was lower, it was found to be higher compared to that of developed countries such as China (1.625 kWh/kg), India (1.684 kWh/kg), Turkey (1.667 kWh/kg), Brazil (1.600 kWh/kg), S. korea (1.667 kWh/kg), USA (1.778 kWh/kg) and Italy (1.714 kWh/kg) (Kaplan, 2010). It means due to inefficiencies of utility systems and equipment the industry under study is spending high energy to produce one unit of product. The high specific energy intensity presents an opportunity to the case study textile industry to reduce energy consumption thus lowering cost of production.

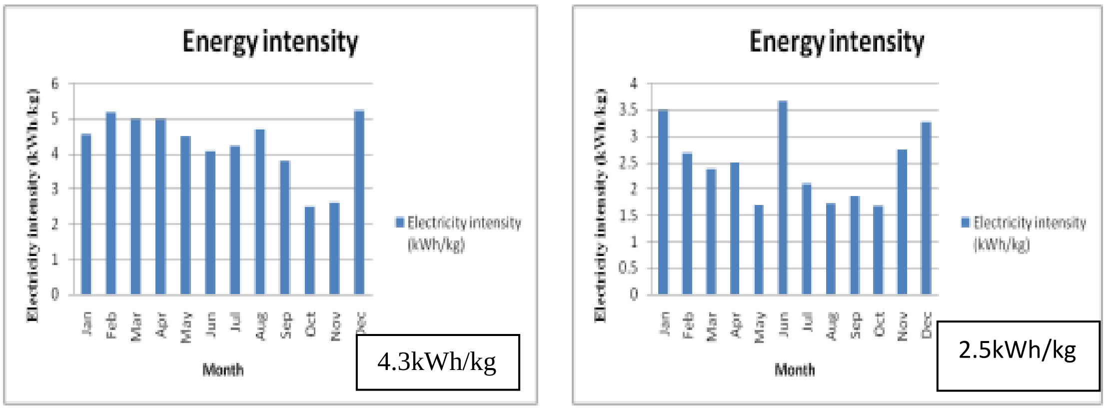


Figure 4.4: Specific electricity consumption for spinning process for the year 2016 and 2017

4.3.3 Statistical Analysis of Energy Use and Production for Spinning Process

It was observed from figure 4.5 that linear relationship exists between production and energy consumption. Since p-value for the spinning is 0.00264 as per the regression summary output which is less than 0.05 (level of significance) implies that the association between energy consumption and production is statistically significant. It was also observed that a unit change in output causes an increase of 109.9 percent change in electricity usage for spinning.

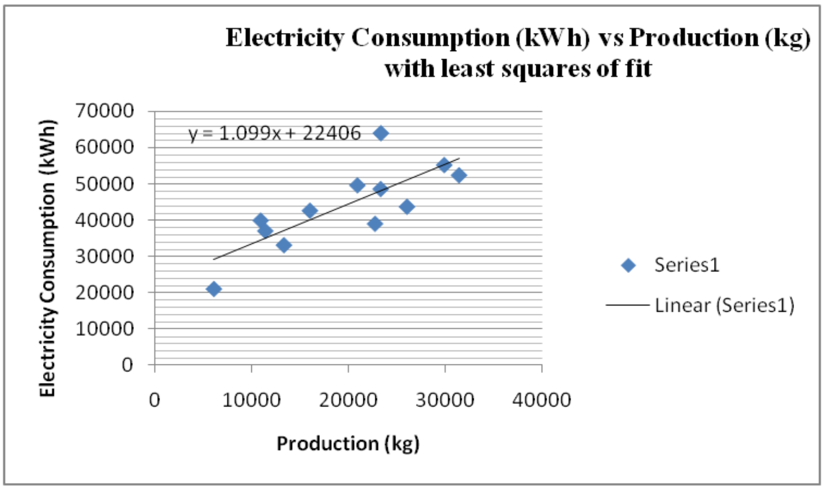


Figure 4.5: Relationship between energy consumption and production for spinning process

Correlation coefficient is the measure of the linear relationship between two variables. The higher the value of '**r**' indicates increased strength of the relationship. The study found correlation coefficient of spinning process to be 0.782 as shown from regression summary output (appendix VIII) which reveals that there continues to be significant potential of energy efficiency potential across all the major processes in spinning.

4.3.4 Capacity Utilization

It was observed from figure 4.6 shows that the relationship between production and specific energy consumption is linear but the slope is negative. It means that with increased output, energy consumption per unit of product is reducing and vice versa.

If production output drops it produces backward movement along the x- axis which signifies increased energy consumption per unit of product. Therefore, production at low capacity utilization is expensive and should be avoided. Sufficient raw materials are necessary to ensure that machines operate at full capacity thus attaining low specific energy intensity. The scatter points about the best fit line reveals great energy efficiency potential with technological best practices.

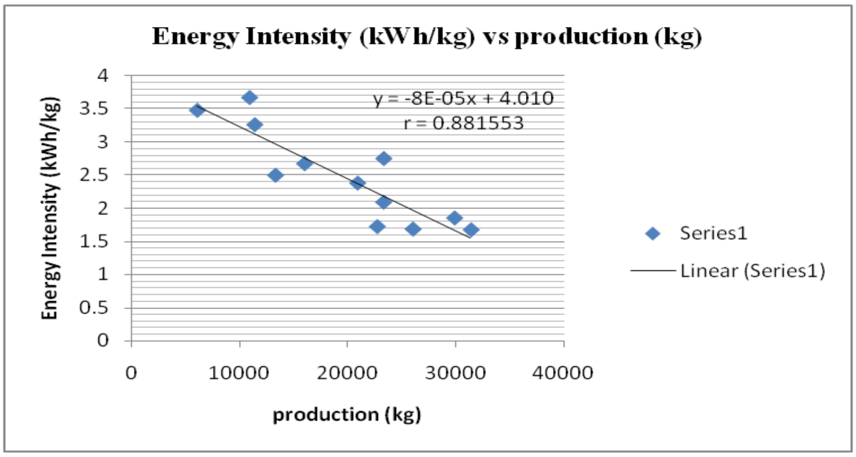


Figure 4.6: Relationship between Production and Specific Energy Consumption for spinning process

4.4 Energy Consumption Analysis for Weaving Process

4.4.1 Energy Consumption Pattern for Weaving

It was observed from figure 4.7 that energy consumed was consistent with production for the two year period. This was due to the fact that weaving process machines used for the two years are similar. Also machines used in weaving are of small capacity minimizing the effects of low material supply unlike spinning process machines which accommodate many production lines.

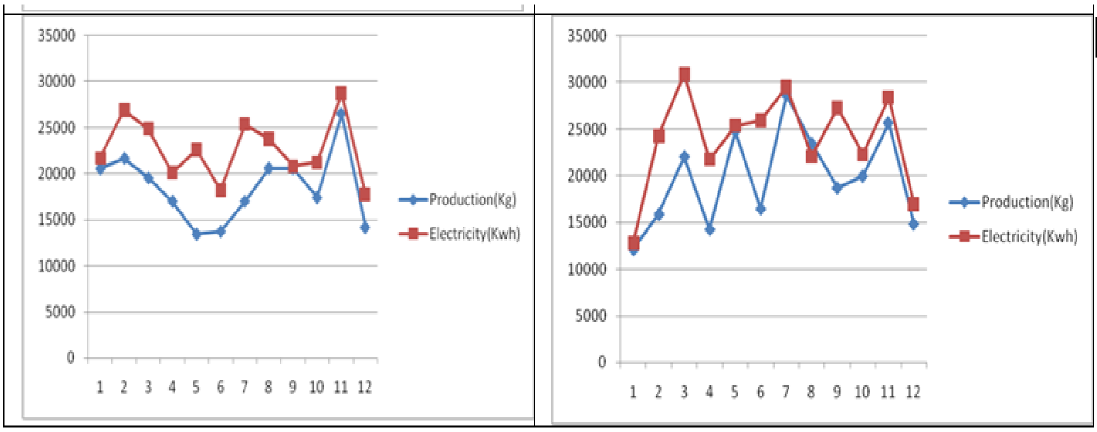


Figure 4.7: Energy consumption pattern for weaving

4.4.2 Specific Energy Intensity for Weaving Process

Results presented in figure 4.8 showed that specific energy intensity for year 2016 and 2017 were similar displaying consistency of energy usage in weaving process. This is mainly due to the fact that weaving machines used in 2016 were similar to that of 2017. The specific energy intensity for weaving was found to be similar to those given in literature. In Turkey specific energy consumption was found to be 1.1950 kWh/kg which was found to be close to the study results (Koc & Cincik, 2010). Therefore, the results display proper utilization of electric energy in weaving process for the case study based on high performing textile industries.

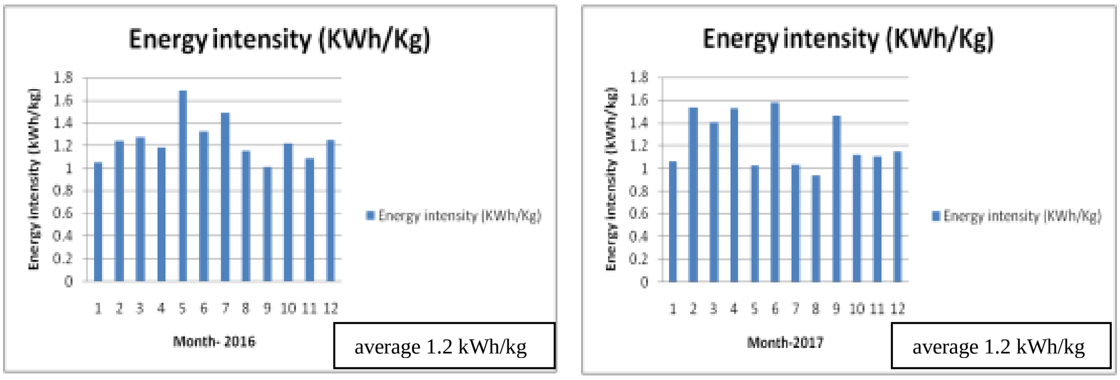


Figure 4.8: Specific electricity consumption for weaving process for the year 2016 and 2017

4.4.3 Statistical Analysis of Energy Use and Production for Weaving Process

It was observed from figure 4.9 that linear relationship exists between production and energy consumption. Since p-value for the spinning was found to be 0.009946 as per the regression summary output which is less than 0.05 (level of significance) indicates that the relationship between energy consumption and production is statistically significant. It was also observed that a unit change in production causes an increase by 71% change in electricity consumption for spinning.

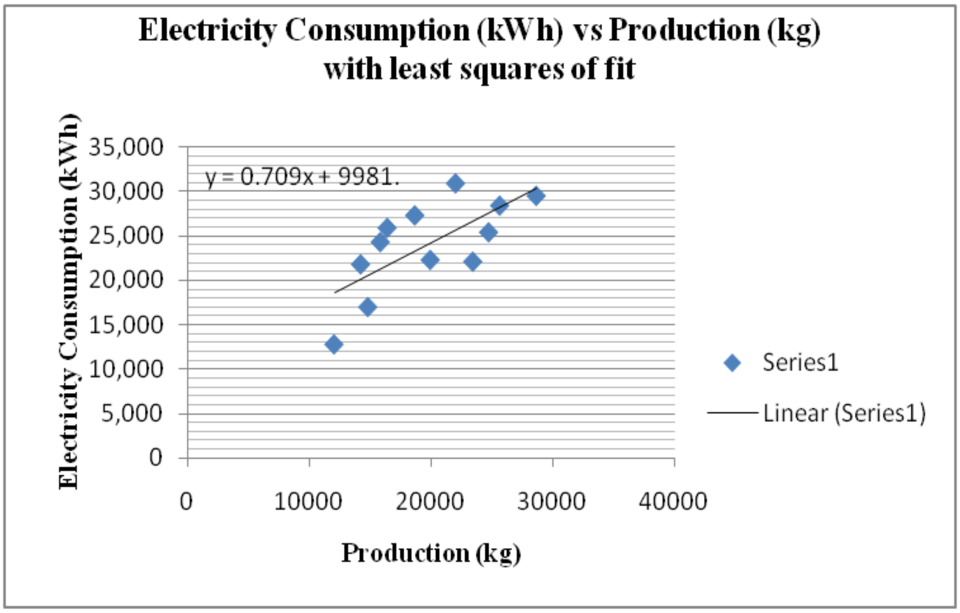


Figure 4.9: Relationship between energy consumption and production for weaving process

The study found correlation coefficient of weaving process to be 0.708245 as shown from regression summary output (appendix VIII) which reveals that there continues to be significant potential of energy efficiency potential across all the major processes in weaving.

4.5 Energy Consumption Analysis for Finishing Process (Wet Processing)

It was observed from figure 4.10 that the linear relationship exists between energy consumption and production. Also noted was that the relationship was close and that approximately one unit of electricity was required to produce one unit of finished fabric in wet processing. The pattern displays consistent energy usage in the production of finished fabric. The results was found to be in line to other studies conducted in similar textile industries.

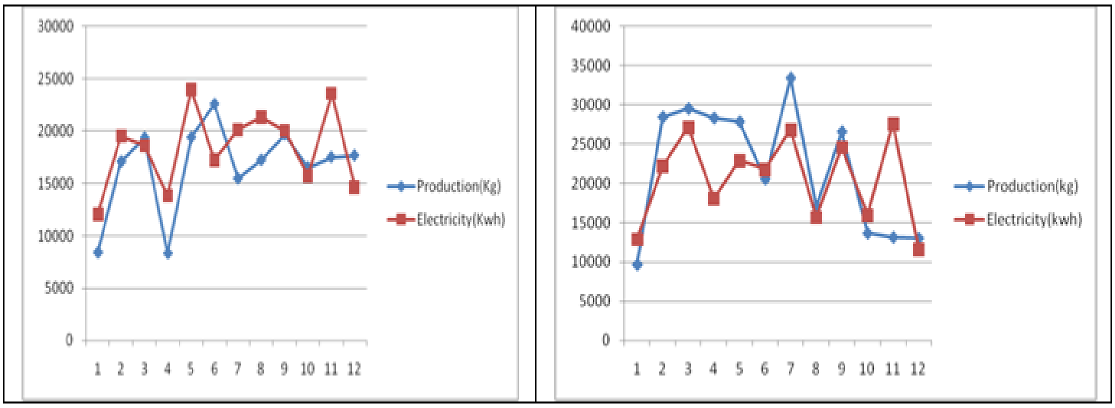


Figure 4.10: Energy consumption pattern for wet processing

4.5.1 Specific Energy Intensity for Wet Processing

Analysis found specific energy intensity for year 2016 to be 1.1 Kwh/Kg and that for 2017 to be 1.0 Kwh/Kg as shown in figure 4.11. It was observed that one unit of electricity is required to produce one unit of finished product in wet processing. The specific energy intensity for wet processing was found to be in line to other studies.

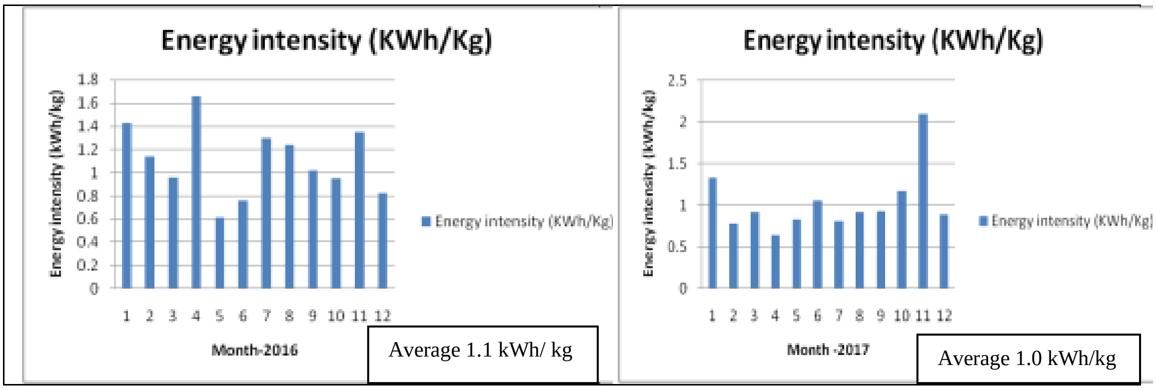


Figure 4.11: Specific electricity consumption for wet processing for the year 2016 and 2017

4.5.2 Statistical Analysis of Energy Use and Production for Wet Processing

It was observed from figure 4.12 that linear relationship exists between production and energy consumption. Since p-value for the spinning is 0.025923 as per the regression summary output (appendix VIII) which is less than 0.05 (level of significance) indicates that the relationship between energy consumption and production is statistically significant. It was also observed that a unit change in production causes an increase by 44% change in electricity consumption.

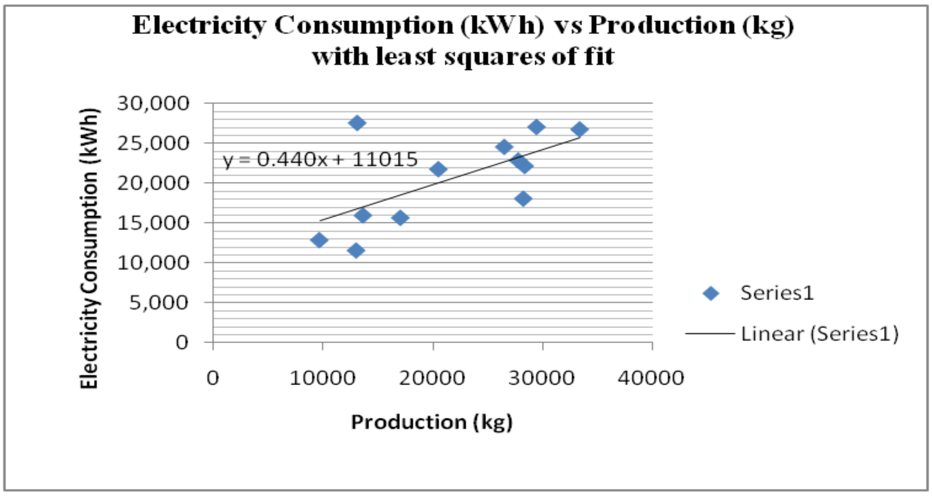


Figure 4.12: Relationship between production and energy consumption for wet processing

The study found correlation coefficient of weaving process to be 0.636928 as shown from regression summary output (appendix VIII) which reveals that there continues to be significant potential of energy efficiency potential across all the major processes in wet processing.

4.6 Performance Analysis of Energy Systems and Energy Saving Opportunities

This section presents an analysis of energy performance of the main energy system which includes; motor systems, steam systems, lighting systems, air compressor system and boiler systems. Energy saving and conservation measures are also discussed.

4.6.1 Steam Distribution Systems

It was observed that substantial steam losses occur due to leakages caused by corroded steam distribution pipes. Also noted was missing insulation in various parts of the steam pipes due to poor maintenance. Figure 4.13 shows the state of steam distribution system in the industry and table 4.1 presents steam distribution system data collected for bare pipes.

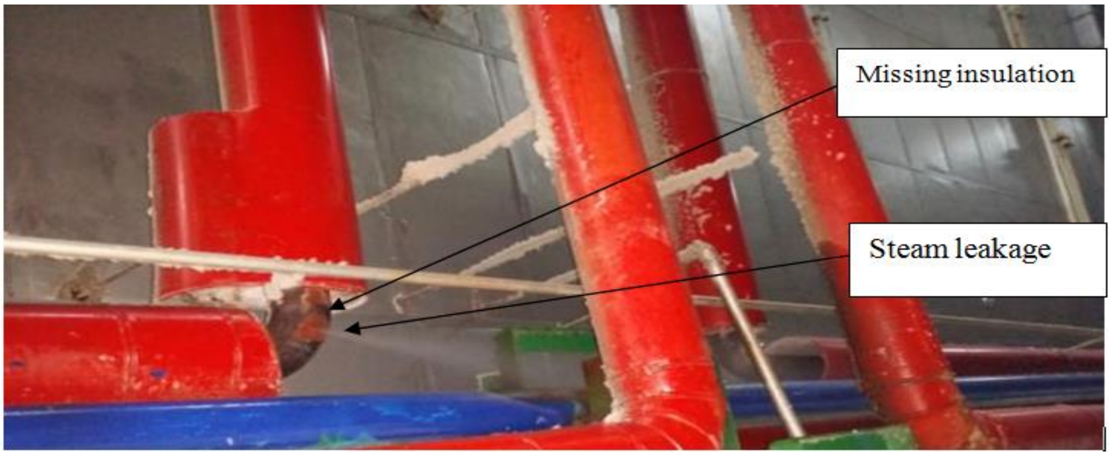


Figure 4.13: Steam leakages on steam distribution systems

Table 4.1: Steam distribution system data collected for bare pipes (2017)

	Pipe 1	Pipe 2
Pipe material	Mild steel	Mild steel
Thermal conductivity coefficient of insulation(mineral wool)	0.044 W/mK	0.044 W/Mk
Thermal conductivity coefficient of pipe	52 W/mK	52 W/mK
Inside heat transfer coefficient(h_i)[1]	1,000 W/m^{2}K	1,000 W/m^{2}K
Outside heat transfer coefficient(h_o)[2]	10 W/m^{2}K	10 W/m^{2}K
Internal Pipe diameter(D_1)	65mm	125mm
External pipe diameter (D_2)	76.1mm	139.7mm
Total length of bare pipe(L)	60M	80M
Pipe thickness(x)	5.55mm	7.35mm
Fluid temperature (t_1)	175^{0}C	175^{0}C
Ambient temperature (t_2)	25^{0}C	25^{0}C
Thickness of lagging	37.5mm	37.5mm
GCV furnace oil	42,738 KJ/kg (10,200kcal/kg)	42,738 KJ/kg (10,200kcal/kg)
Running hours p.a for thermo boiler	2,400	2,400
Cost of furnace oil (Ksh/kg)	57	57
Cost of insulation material (Ksh/m)	2,000	2,000

[1]Gases in free convection (appendix vii) [2]Oil flowing in tubes (appendix vii)

Heat Loss

Heat losses with lagging (pipe 1)

Using steam distribution data above (table 4.10), the overall thermal resistance per unit length is given by equation 3.16;

$$R_t = R_i + R_o + R_p + R_{ins}$$

R_t= 2.6970mK/W

Heat loss per meter (equation 3.17),

$$Q = \frac{T-t}{R_t} \quad \text{(W/m)}$$

$Q =$**55.62 W/m**

Heat losses without lagging (pipe 1)

For bare pipe, the overall thermal resistance is given by;

$$R_t = R_i + R_o + R_p$$

R_t= 0.2160 mK/W

Heat loss per meter (equation 3.17),

$$Q = \frac{T-t}{R_t} \quad \text{(W/m)}$$

$Q =$ **694.33 W/m**

Energy savings on lagging

From the calculations above it can be shown that significant energy saving potential exists with lagging of bare pipes in the industry. The 37.5 mm thick mineral wool lagging reduces heat loss from 694.33 W/m to 55.62 W/m which is a great benefit.

Savings= 694.33 – 55.62

= 638.71W/m

$$Energy\ saving\ potential = \frac{638.71w/m}{694.33w/m}$$

= 91%

In Rivatex East Africa Ltd, from measurement the length of 65 mm diameter bare pipes is 60m.

For 60m bare pipes, the energy saving is;

=638.71×60

=38,322.6W

= 38.3226KJ/s

Amount of fuel savings per hour

$$= \frac{38.3226\, KJ/S \times 3{,}600}{42{,}738\, KJ/kg}$$

= 3.228kg/hr

Amount of fuel savings per annum

= 3.228× 2,400

= 7,747.2 kg

Potential savings for pipe 1 in Ksh=7,747.2× 57

= Ksh 441,590.40

Using the same procedure for pipe 2, the overall thermal resistance per unit length is (equation 3.16);

$$R_t = R_i + R_o + R_p + R_{ins}$$

R_t=1.705592mK/W

Heat loss per meter (equation 3.17),

$$Q = \frac{T-t}{R_t} \text{(W/m)}$$

Q= **87.946 W/m**

Heat losses without lagging (pipe 2)

For bare pipe, the overall thermal resistance is given by;

$$R_t = R_i + R_o + R_p$$

R_t= 0.151142 mK/W

Heat loss per meter (equation 3.17),

$$Q = \frac{T-t}{R_t}\text{(W/m)}$$

Q **= 992.444 W/m**

Energy savings on lagging

From the calculations above it can be shown that significant energy saving potential exists with lagging of bare pipes in the industry. The 37.5 mm thick mineral wool insulation reduces heat loss from 992.444 W/m to 87.946 W/m which is a great benefit.

Savings= 992.444 – 87.946

= 904.5W/m

$$Energy\ saving\ potential = \frac{904.5w/m}{992.444w/m}$$

= 91%

In Rivatex EA Ltd, from measurement the length of 125 mm diameter bare pipes is 80m.

For 80m bare pipes, the energy saving is;

=904.5×80

=72,360W

= 72.36KJ/s

Amount of fuel savings per hour

$$= \frac{72.36\ KJ/S \times 3{,}600}{42{,}738\ KJ/kg}$$

= 6.095kg/hr

Amount of fuel savings per annum

= 6.095× 2,400

= 14,628 kg

Potential savings for pipe 2 in Ksh=14,628× 57

= **Ksh 833,796**

Total savings for pipe 1 and pipe 2= 441,590.40 +833,796

= **Ksh 1,275,386.40**

Cost of investment

Cost of insulation = 2,000 ×140m

=Ksh 280,000

Cost of labour = Ksh 50,000

Total cost = **Ksh 330,000**

Simple payback period

$$\mathrm{SPP} = \frac{\text{Cost of investment}}{\text{Annual savings}}$$

$$= \frac{330{,}000}{1{,}275{,}386.40}$$

= 0.3 years (approx. 4months)

4.6.2 Boiler System

It was noted that insulation linings of wood fired boiler was missing due to poor maintenance. Hot water leakages reduce the efficiency of the boiler to generate steam. Figure 4.14 shows leakage of hot water at the bottom of the boiler.

a) Performance Evaluation of Wood Fire-Tube Boiler

The efficiency of boiler reduces with time due to poor operation and maintenance, poor combustion and heat transfer fouling. The quality of fuel and water quality used in the boiler also affects the efficiency. Analysis of boiler efficiency was important to determine deviation of boiler efficiency from the expected performance for corrective action.

Figure 4.14: Leakages of hot water from wood fire-tube boiler

Table 4.2: Measurement results for wood fired tube boiler (2017)

Flue gas analysis data- Testo 310				
	Sample 1	Sample 2	Sample 3	Average
Flue gas temperature, T_f	395.1°C	329.7°C	389.3°C	371.4°C
Oxygen, O_2	17.7%	15.0%	16.5%	16.4%
Carbon monoxide, CO	33 ppm	28ppm	29ppm	30ppm
qA[1]	80.9%	79%	80%	80%
Undiluted CO	213 ppm	188ppm	206ppm	202.3ppm
Carbon dioxide, CO_2	3.19%	5.8%	3.8%	4.3%
Ambient temperature, T_a	23.0°C	24.6°C	24.0°C	23.9°C
Combustion efficiency, EFF	19.0%	21%	20%	20%
Lambda (Air ratio)	6.36	3.50	4.3	4.72
Relative humidity				50%
Dry bulb temperature(°C)				23.9°C
Wet bulb temperature (°C)				17°C
Humidity of air kg/kg of dry air[2]				0.009
Specific heat of flue gas in kCal/kg^{0}C (C_p)[3]				0.25
Specific heat of superheated steam in kCal/kg^{0}C (C_p)[4]				0.48

[1]Flue gas loss without due consideration of the calorific value range
[2]psychometric chart (appendix VI)
[3]steam table (dry air)
[4]steam table (vapour)

Boiler Efficiency-Indirect Method (Heat Loss Method)

The instantaneous energy balance for the wood fire tube boiler was done by taking three samples at intervals of 5 minutes of the flue gas from the boiler stack using an electronic flue gas analyzer. The measurements recorded by the flue gas analyzer include oxygen (O_2) content, carbon dioxide (CO_2) content, Carbon monoxide (CO) and flue gas temperature. Measurement results for wood fire tube boiler are given in table 4.2. Based on the results of the measurements shown in table 4.2, the following observations were made; Combustion analysis performed on wood fire tube boiler shows poor combustion due to major deviation of measured parameters against optimal flue gas composition given in table 4.3. Flue gas temperature leaving the chimney was found to be high due to blocked fire tubes and fouling. High amount of oxygen is due to excess air into the boiler through openings along the wall of the boiler. Also noted from flue gas analysis data in table 4.2 was that air-ratio was found to be 4.72 times higher than the stoichiometric equivalence factor ($\lambda = 1.00$)

Table 4.3: Measured parameters against optimal flue gas composition

Component	**Actual value**	**Optimal/standard value**
Oxygen, O_2	16.4%	5.8%
Carbon dioxide, CO_2	4.3%	20.3%
Flue gas temperature, ^oC	371.4^oC	200^oC

Source: Author's compilation

Boiler Efficiency Calculations-Indirect Method

Step 1- The theoretical air requirement

The theoretical air requirement =

$$[(11.6\times C) + \{34.8 \times (H2\text{-}O2/8) + (4.35\times S)\}]/100\text{kg/kg of fuel} \qquad (4.1)$$

= 3.67 kg of air/kg of fuel

Step 2 – The percentage of excess air supplied

% Excess Air Supplied (EA) =

$[O_2\% / (21-O_2\%)] \times 100$ (from flue gas analysis) (4.2)

= 356.5%

Step 3- The actual mass of air supplied

Actual mass of air supplied/kg of fuel (AAS) =

$[1+EA/100] \times$ Theoretical Air (4.3)

= 16.75 kg of air/kg of fuel

Mass of flue gas (m)/kg of fuel = mass of actual air supplied/kg of fuel + 1 kg of fuel

= 17.75 kg/kg of fuel

Step 4- The boiler losses (L1)

i. **Dry flue gas loss**

% heat loss due to dry flue gas =

$m \times C_p \times (T_f - T_a) \times 100$ /GCV of Fuel (4.4)

Where,

m =Mass of dry flue gas in kg/kg of fuel

C_p =Specific heat of flue gas in kCal/kg

T_f=Flue gas temperature in ^oC

T_a=Ambient temperature in oC

= 58.97 %

ii. **Heat loss due to evaporation of water formed due to H_2 in fuel (L2)**

% heat loss due to hydrogen in fuel =

$(9 \times H_2 \times \{584 + C_p (T_f - T_a)\}$/GCV of fuel) $\times 100$

(4.5)

Where,

H_2 =kg of hydrogen present in fuel on 1 kg basis

C_p =Specific heat of superheated steam in kCal/kg^oC

T_f =Flue gas temperature in ^oC

T_a=Ambient temperature in ^oC

584=Latent heat corresponding to partial pressure of water vapour

= **9.61%**

iii. Heat loss due to moisture present in fuel (L3)

% Heat loss due to moisture present in air =

$$(M\times \{584 + C_p (T_f - T_a)\} /GCV \text{ of Fuel}) \times 100 \quad (4.6)$$

Where,

M=kg of moisture in fuel in 1 kg basis

C_p=Specific heat of superheated steam in kCal/kg^oC

T_f =Flue gas temperature in ^oC

T_a=Ambient temperature in ^oC

584=Latent heat corresponding to partial pressure of water vapour

= **11.48%**

iv. Heat loss due to moisture present in air (L4)

$$\% \text{ Heat loss due to moisture in air} = \frac{AAS \times humidity \times C_p \times (T_f - T_a)}{GCV\ of\ fuel} \times 100 \quad (4.7)$$

Where,

AAS=Actual mass of air supplied per kg of fuel

Humidity factor=kg of water/kg of dry air

C_p=Specific heat of superheated steam in kCal/kg^oC

T_f=Flue gas temperature in ^oC

T_a=Ambient temperature in ^oC (dry bulb)

$= 0.\mathbf{96\%}$

v. Heat loss due to incomplete combustion(L5)

% heat loss due to incomplete combustion =

$$\frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV\ of\ fuel} \times 100 \quad (4.8)$$

Where,

CO = volume of CO in flue gas (%)

CO2 = actual volume of CO2 in flue gas (%)

C = carbon content kg/kg of fuel

= **0.05%**

vi. Heat loss due to radiation and other unaccounted losses (L6)

For industrial fire tube boiler surface loss and other unaccounted losses ranges from **1.5** to 2.5% based on literature.

vii. Heat loss due to unburnt in bottom ash (L7)

% heat loss due to unburnt in bottom ash = (Total bottom ash collected per kg of fuel burnt × GCV of bottom ash/GCV of Fuel) ×100 (4.9)

= 0.07%

viii. Heat loss due to unburnt in fly ash (L8)

% heat loss due to unburnt in fly ash

= (Total ash collected per kg of fuel burnt × GCV of fly ash /GCV of Fuel) ×100

(4.10)

=0.006%

Boiler efficiency by indirect method = 100 - $\sum_{i=1}^{8} L$**= 17.35 %**

Energy saving opportunities in boiler system

The boiler heat loss results calculated above indicates that the major losses in the system are due to dry flue gas 58.97%, followed by losses due to moisture 11.48% and loss due to hydrogen in fuel 9.62%. According to Parvez (2017)typical fire tube boiler efficiency is 75%. Improving the efficiency of the boiler under study is a clear opportunity to conserve energy in the industry (Tucki et al., 2019). The clear options of improving boiler efficiency are discussed below;

1. **Excess air control**

   If the percentage of excess air is adjusted to optimum levels as per table 4.3 to obtain the required CO_2 percentage (15.5%) and oxygen (5%), then calculated boiler efficiency would be improved to 56.98% as shown below.

Step 1- The theoretical air requirement (equation 4.1)

The theoretical air requirement =

$[(11.6\times C) + \{34.8 \times (H_2-O_2/8) + (4.35\times S)\}]/100$kg/kg of fuel (from fuel analysis)

= 3.67 kg of air/kg of fuel

Step 2 – The percentage of excess air supplied

For optimum flue gas composition oxygen (O_2) represents 5% thus substituting in equation 4.2,

% Excess Air Supplied (EA) = $[O_2\% / (21-O_2\%)] \times 100$ (from flue gas analysis)

= 31.25%

Step 3- The actual mass of air supplied

Then substituting 31.25% excess air (EA) supplied in equation 4.3 actual mass of air supplied is calculated as follows,

Actual mass of air supplied/kg of fuel (AAS) = [1+EA/100] × Theoretical Air

= 4.82 kg of air/kg of fuel

Mass of flue gas (m)/kg of fuel = mass of actual air supplied/kg of fuel + 1 kg of fuel

$= 4.82 + 1$

$= 5.82$ kg/kg of fuel

Step 4- The boiler losses (L1)

i. Dry flue gas loss

Substituting mass of dry flue gas in equation 4.4 with 5.82 kg/kg of fuel, then heat loss due to dry flue gas is calculated.

% heat loss due to dry flue gas = $m \times C_p \times (T_f - T_a) \times 100$ /GCV of Fuel

Where,

m =Mass of dry flue gas in kg/kg of fuel

C_p = Specific heat of flue gas in kCal/kg

T_f = Flue gas temperature in ^oC

T_a=Ambient temperature in ^oC

= 19.34 %

The reduction of dry flue gas loss from 58.97% to 19.34% improves boiler efficiency to 56.98% as shown below,

Boiler efficiency = $100 - \sum_{i=1}^{8} L$

= 56.98 %

Therefore, the annual fuel savings achieved by improving the boiler combustion efficiency to be 56.98% is estimated as follows;

Fuel saving = U × [1- (η before/ η after)] (4.11)

Where,

U: annual fuel usage by boiler, kg/yr

η before: combustion efficiency before improvement

η after: combustion efficiency after improvement

Annual fuel usage by boiler, kg/yr (U)

Average usage per day= 6,292kg

Usage per year= 6,292kg× 25 days per month×12 months

= 1,887,620 kg/year

Fuel saving = U × [1- (η before/ η after)]

= 1,887,620× [1- (17.35/ 56.98)]

= 1,312,853 kg/year

= 1,313 ton/year

$$Energy\ saving\ potential = \frac{1313\ ton/year}{1887.62\ ton/year}$$

= 69%

For 50% achievement, then annual fuel saving is calculated,

Fuel savings in Ksh/year = 1,313 ton × 2,200 Ksh×$\frac{50}{100}$

= Ksh. 1,444,300

Estimated cost of investment (Ksh)

Invest in supply and installation of on-line oxygen analyzer and interlocking to adjust fan speed to suit the recommended oxygen percentage in flue gas (5%) and excess air of 30%. The fans will be equipped with Variable Speed Drives. The estimated cost of investment is Ksh 1,500,000

- Online oxygen analyzer 1,000,000
- Variable speed drive 500,000

Simple payback period (years) = investment cost/savings per annum

= 1,500,000/1,444,300

= 1 years

2. **Reducing moisture content of wood fuel**

The efficiency of boiler is greatly affected by the quality of fuel. Figure 4.15 shows fresh wood fuel used by the case study industry to produce steam in the boiler. Proper drying and preservation of wood fuel is necessary to improve quality. Moisture free fuel should be fed to the boiler so that no amount of heat is lost in removing the moisture from fuel and all the heat can be efficiently used to convert water to steam. Proper drying of fuel also improves fuel properties and gross calorific value thus improving boiler efficiency. Firewood should ideally have a moisture content of below 25% of total weight by the time it is used.

Figure 4.15: Fresh wood fuel used

The cheapest way to dry firewood is by natural drying. The logs are cross cut and then split into firewood as soon as possible after harvesting, and stored in an open place where sun and wind can dry the fuel. Firewood needs to be covered on top or preferably stored under a roof to keep out rain, and should be lifted out of direct ground contact. This will improve the air flow through the wood (Kofman P.D, 2013). If the moisture content of wood fuel is improved to 20% (table 4.4), then the savings is calculated as follows;

% Heat loss due to moisture present in air =

$(M \times \{584+C_p(T_f-T_a)\} / \text{GCV of Fuel}) \times 100$

Table 4.4: Wood composition (% wt) and GCV

% wt water (moisture content)	0	**20**	40	60
C	50.30	**40.24**	30.18	20
H	6.20	**4.96**	3.72	2.7
O	43.08	**34.46**	25.85	17
N	0.04	**0.03**	0.02	0.01
S	0.00	**0.00**	0.00	0.00
Ash	0.37	**0.31**	0.23	0.15
Total	100	**100**	100	100
GCV(KJ/kg)	19,900	**15,400**	10,950	6,500

(Isidoro Martinez, 1995-2022)

Where,

M=kg of moisture in fuel in 1 kg basis

C_p=Specific heat of superheated steam in kCal/kg^{o}C

T_f =Flue gas temperature in ^{o}C

T_a=Ambient temperature in ^{o}C

584=Latent heat corresponding to partial pressure of water vapour

= **4.09%**

Improving moisture content of wood fuel used from 40% to 20% reduces losses due to moisture from 11.48% to 4.09%, and boilers efficiency improves from 17.35% to 24.74%, therefore provision of wood drying is necessary before supplying to the combustion chamber. Wood logs should be split to smaller sizes and placed inside a properly designed shade which allows proper stacking. It is important also to use dried wood on first come first serve basis to ensure that most dry wood are used first. Estimated fuel saving on drying of wood fuel is calculated using equation 4.11,

Fuel saving = U × [1- (η before/ η after)]

Fuel saving = 1,887,620 × [1- (17.35/ 24.74)]

= 563,844 kg/year

Fuel cost savings Ksh/year = 563.844 ton × Ksh. 2,200

=**Ksh. 1,238,600**

Estimated cost of investment

The materials required in setting up a shade for firewood includes iron sheets, posts timber and nails.

150 iron sheets@700 = Ksh 105,000

200 posts @300 =Ksh 60,000

Timber and nails = Ksh 500,000

Labour cost = Ksh 230,000

The estimated cost of materials and labour is approximately Ksh 895,000.

Simple payback period

Simple payback period= cost of investment/ savings per year

= Ksh 895,000/Ksh 1,238,600

= **0.7 years**

Other Energy saving opportunities identified;

(i) Proper insulation of the boiler walls and piping's to reduce radiation and convection heat losses to the surrounding. The boiler insulation should be assessed and replaced where it is insufficient or showing signs of degradation.

Figure 4.16: Combustion chamber of wood fire-tube boiler

Figure 4.17: Blocked fire tubes of wood fire-tube boiler

(ii) Boiler maintenance should be done regularly (daily, weekly, monthly and semi-annually) and removing the scale and ash deposits on the fire tubes should be given priority as these deposits act as insulation thus preventing heat transfer between flue gas and boiler water. High percentage of heat losses is due to the high temperature of dry flue gases leaving the boiler.

(iii) Leakages of hot water and steam are significant source of heat loss from the boiler causing unnecessary consumption of extra wood fuel. Fixing leakages by repairing pipes is essential to minimize steam losses.

(iv) Waste heat recovery should be employed to utilize high temperature of flue gases which is currently vented to the atmosphere. Flue gas temperatures above 200^oC can be used to increase boiler feed water temperature or dry wood fuel to achieve moisture content below 25^oC. Significant energy savings can be achieved from the reuse of the high temperature condensate.

(v) Automation of boiler (installation of steam meters) to better understand the steam demand profile of the factory, there is a need to install a steam flow meter so that the boilers' operation can be better managed.

a) Performance assessment of thermo boiler

Figure 4.18: Ignition point of Thermo oil boiler

Flue gas data presented in table 4.5 was collected by taking three samples of flue gas and calculating the average.

Boiler efficiency- indirect method (heat loss method)

Step 1- The theoretical air requirement (equation4.1)

The theoretical air requirement =

$[(11.6\times C) + \{34.8 \times (H_2\text{-}O_2/8) + (4.35\times S)\}]/100$kg/kg of fuel (from fuel analysis)

= 12.80 kg of air/kg of fuel

Step 2 – The percentage of excess air supplied (equation 4.2)

% Excess Air Supplied (EA) = [O_2% / (21-O_2%)] ×100 (from flue gas analysis)

= 6.06%

Step 3- The actual mass of air supplied (equation 4.3)

Actual mass of air supplied/kg of fuel (AAS) = [1+EA/100] × Theoretical Air

= 13.58 kg of air/kg of fuel

Mass of flue gas (m)/kg of fuel = mass of actual air supplied/kg of fuel + 1 kg of fuel

= 13.58 + 1

= 14.58 kg/kg of fuel

Table 4.5: Nameplate and measured flue gas analysis data for thermo oil boiler (2017)

Type	V1600 (oil fired)			
Year of construction	2015			
Output	1860 KW			
Flow rate	115m^3/h			
Fuel	Heavy oil			
Maximum pressure	10 bar			
Maximum temperature	300^{o}C			
Volume	1695 L			
GCV heavy oil	10200 kcal/kg			
Enthalpy of steam	660 kcal/kg			
Relative humidity	30%			
Dry bulb temperature(^{o}C)	30.6^{o}C			
Wet bulb temperature(^{o}C)	18(^{o}C)			
Humidity of air kg/kg of dry air[1]	0.008			
Specific heat of flue gas in kCal/kg^{0}C (C_p)[2]	0.24			
Specific heat of superheated steam in kCal/kg^{0}C (C_p)[3]	0.46			
Flue gas analysis data- Testo 310				
	Sample 1	Sample 2	Sample 3	Average
Flue gas temperature, T_f	217.2^{0}C	199.5^{0}C	220.6^{0}C	212.4^{0}C
Oxygen, O_2	1.1%	1.0%	1.6%	1.2%
Carbon monoxide, CO	7532ppm	4774 ppm	5993 ppm	6100ppm
qA[4]	7.5%	6.8%	7.8%	7.4%
Undiluted CO	7948 ppm	5012	6487	6482
Carbon dioxide, CO_2	15.07%	15.14%	14.69%	15.0%
Ambient temperature, T_a	30.6^{o}C	30.6^{o}C	30.6^{o}C	30.6^{o}C
Combustion efficiency, EFF	92.5%	93.2	92.2	92.6%
Lambda (Air ratio)	1.05	1.05	1.08	1.06

[1]psychometric chart (appendix VI)
[2]steam table (dry air)
[3]steam table (vapour)
[4]Flue gas loss without due consideration of the calorific value range

Step 4- The boiler losses (L1)

i. **Dry flue gas loss**

Dry flue gas loss was calculated using equation 4.4.

% heat loss due to dry flue gas = $m \times C_p \times (T_f - T_a) \times 100$ /GCV of Fuel

= 6.24%

ii. **Heat loss due to evaporation of water formed due to H_2 in fuel (L2)**

Heat loss due to evaporation was calculated using equation 4.5.

% heat loss due to hydrogen in fuel = $(9 \times H_2 \times \{584 + C_p (T_f - T_a)\}$/GCV of fuel) $\times 100$

= **5.24%**

iii. **Heat loss due to moisture present in fuel (L3)**

Heat loss due to moisture was calculated using equation 4.6.

% Heat loss due to moisture present in air =

$(M \times \{584 + C_p(T_f - T_a)\}$ /GCV of Fuel)x100

= **0.03%**

iv. **Heat loss due to moisture present in air (L4)**

Heat loss due to moisture present in air was calculated using equation 4.6.

% Heat loss due to moisture in air = $\frac{AAS \times humidity \times C_p \times (T_f - T_a)}{GCV\ of\ fuel} \times 100$

= 0.09%

v. **Heat loss due to incomplete combustion(L5)**

Heat loss due to incomplete combustion was calculated using equation 4.7.

% heat loss due to incomplete combustion = $\frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{\text{GCV of fuel}} \times 100$

= 1.8%

vi. Heat loss due to radiation and other unaccounted losses (L6)

Surface loss and other unaccounted losses are assumed based on the type and size of the boiler. For industrial oil fired boiler = **0.5%** -1%

Boiler efficiency by indirect method = 100 - $\sum_{i=1}^{6} L$) = **86.1%**

Based on the results of the measurements presented in table 4.5, the following observations were made;

1. Combustion analysis performed on thermo boiler shows good combustion due to marginal deviation of measured parameters against optimal flue gas composition as shown in table 4.6;

Table 4.6: Summary of Thermo oil boiler performance

Parameters	**Theoretical**	**Measured**
CO2 in dry flue gas (%)	15%	15%
Flue gas oxygen content (%)	1.2%	1.2%
Air fuel ratio (kg of air /kg of fuel)	13.90	13.58
Mass of flue gas (kg of flue gas/kg of fuel)	14.30	14.58
Boiler efficiency (%)	80-90	86.1

Source: Author's compilation

The results on energy efficiency of thermo oil boiler through heat loss method showed good performance since it is within the expected range of 80- 90% efficiency of well-maintained oil boilers. The percentage level of CO_2 present in flue gas as per the flue gas analyzer indicates 15% which is consistent with theoretical CO_2 in dry flue gas shown in table 2.5; in fact, literature indicates CO_2 in flue gas so far achieved in practice is between 9-14%. Also the air fuel ratio and mass of flue gas is consistent with theoretical values. The study found the performance of thermo oil boiler excellent and recommended slight air ratio adjustments to reduce smoke emitted to the atmosphere.

4.6.3 Lighting Systems

Lighting system energy consumption is minimal compared to other systems such as motor system and air compressor system in the industry but room for energy saving opportunities exists. Incorporation of modern energy efficient lamps is an opportunity to achieve energy efficiency in lighting. The main objective of efficient lighting is to provide the required lighting effect at the lowest power consumption. Table 4.7 shows the existing installed number of luminaires in the case study industry.

Lighting measurements for the factory under study taken with lux meter showed poor illumination levels compared to the recommended standards as shown in table 2.7 and table 2.8. Table 4.8 compares standard illumination levels and measured illumination levels.

From observation it was noted that most of the lamps were not working and some are dirty which contributed to poor illumination levels recorded.

The energy saving opportunities identified for lighting systems include;

(a) Adjusting the number of luminaires to recommended levels

The optimum number of luminaires required in order to achieve standard illumination levels is calculated as follows (equation 3.6);

$N = (E\times A)/\ (n\times F\times UF\times\ MF)$

Using the above equation, recommended number of lamps for various departments is calculated as follows;

Spinning

Existing Lamps = 490, existing luminaires (N) = 246, Recommended lux level = 300, UF=0.8, MF= 0.9, Area = 1,500m^2

$N = (E\times A)/\ (n\times F\times UF\times\ MF)$

$N= (300\times 1500)/\ (2\times 1500\times 0.8\times\ 0.9)$

Number of luminaires =**208**

The number of lamps = 208×2

= **416**

Table 4.7: Existing lighting data for the industry

Department	Number of lamps (58W)	Total KW	HOURS	Total KWH/day
Spinning area	490	28.42	16	454.72
Spinning lab	4	0.232	8	1.856
Spinning mechanic store	4	0.232	16	3.712
Spinning managers office	8	0.464	8	3.712
Spinning store	4	0.232	16	3.712
Factory manager office	8	0.464	8	3.712
Spinning department toilets	8	0.464	16	7.424
Preparation clerk office	1	0.058	8	0.464
Preparation mechanic room	1	0.058	16	0.928
Weaving manager office	4	0.232	8	1.856
Weaving department toilets	8	0.464	16	7.424
Sizing and preparation	232	13.456	16	215.296
Weaving area	498	28.884	16	462.144
Drawing in room	2	0.116	8	0.928
Weaving supervisor office	1	0.058	16	0.928
Weaving clerk’s office	2	0.116	8	0.928
Grey cloth inspection	12	0.696	8	5.568
Processing area	29	1.682	16	26.912
Boiler room	2	0.116	16	1.856
Air compressor room	2	0.116	16	1.856
ICT	2	0.116	8	0.928
Quality control office	2	0.116	8	0.928
Kitchen	28	1.624	8	12.992
Latrines	8	0.464	16	7.424
HR office	10	0.58	8	4.64
Research manager/training office	30	1.74	8	13.92
Workshop	42	2.436	8	19.488
Main store	8	0.464	8	3.712
Processing manager office	4	0.232	8	1.856
Assistant manager office	2	0.116	16	1.856
Processing mechanic store	2	0.116	16	1.856
Colour kitchen	20	1.16	8	9.28
Designing room	12	0.696	8	5.568
Wood boiler area	2	0.116	8	0.928
Making up	20	1.16	8	9.28
TOTAL	1512	87.696	384	1300.592

Table 4.8: Lux meter measured illumination levels for the industry (2017)

Department	Area (m^2)	Standard illumination levels(lux)	Measured illumination levels (lux)
Spinning	1,500	300	16.4
Weaving	1,500	200	9
Sizing and Preparation	500	400	31
Wet processing	1,000	200	22
Workshop	100	750	46

Applying equation 3.6 for weaving, sizing and preparation, wet processing and workshop, recommended number of luminaires is given in table 4.9.

Adjusting the number of lamps to recommended levels as per table 4.9 improves illumination levels to standard and energy saving of Ksh 1,369,712 per annum can be achieved. It is important to observe standard illumination levels in order to improve employee performance and safe working environment.

Table 4.9: Recommended number of luminaires

Department	Standard lux levels (lux)	Measured lux levels (lux)	Usage time (hrs)	No. of lamps working (58w)	Installed number lamps (58w)	Energy used (KWh/year)	Recommended number lamps(58w)	Energy used (KWh/year)	Energy saving (KWh/year)	Cost savings (Ksh/year)
Spinning	300	16.4	16	75	490	136,416	416	115,814	20,602	829,632
Weaving	200	9	16	45	498	138,643	278	77,395	61,248	1,224,960
Sizing and Preparation	400	31	16	42	232	64,588	185	51,504	13,084	261,680
Wet processing	200	22	16	19	29	8,074	185	51,504	-43,430	-868,600
Workshop	750	46	8	10	42	5,846	70	9,744	-3,898	-77,960
Total					1,291	353,567	1,134	305,961	47,606	1,369,712

(b) Replace T-12 Fluorescent with T-8 LED lamps

Many of the lamps used in the factory are T-12 fluorescent lamps. Energy saving can be achieved if the existing lamps are phased out and replaced with LED lamps.

Table 4.10: Energy savings on use of T-8LED lamps

	Existing situation	**Recommended**
Type of lamps	T-12 Fluorescent lamps	T-8 LED lamps
Lamp watts	58	20
Recommended No. of lamps as per table 4.8	1,134	1,134
Annual energy usage kWh/year	305,961	105,504
Savings		
Annual energy savings kWh/year	200,457	
Annual cost savings Ksh/year	200,457×20 = 4,009,140	
Investment cost (1,134 lamps× Ksh 1,700)	1,927,800	
Simple payback period=cost of investment/annual savings	**0.5 years or 6months**	

The replacement can be done gradually by replacing burn out lamps with energy saving lamps in order to avoid any extra cost. If the industry utilizes T-8 LED lamps of 20watts each then the annual savings can be calculated as shown in table 4.10.

$$Energy\ saving\ potential = \frac{200{,}457 kwh/year}{305{,}961 kwh/year}$$

= 66%

Other Energy efficient measures for lighting

i) Existing skylights at the finishing department needs to be cleaned to improve illumination level. There’s need to install more skylights to avoid use of artificial lighting during the day hence minimizing lighting costs.

ii) Installation of skylights in spinning, sizing and weaving departments is necessary to avoid usage of artificial lighting during the day.

4.6.4 Air Compressor System

The power consumption measured was observed to be varying between 40.57kW to 65.23 kW with an average consumption of 49.88kW as shown in figure 11. The rated power of the motor is 75 kW and from the above measurement the motor is operating at 66.5% of the rated power.

Isothermal Efficiency = Isothermal power / Input power

Isothermal power is the least power required to compress the air assuming isothermal conditions.

$$Isothermal\ power(kW) = \frac{P_1 \times Q_f \times log_e r}{36.7}$$

Sample Recording: Loading trend of Rotary screw air compressor GA-808 (AC current/voltage logger, sample interval is 1min)

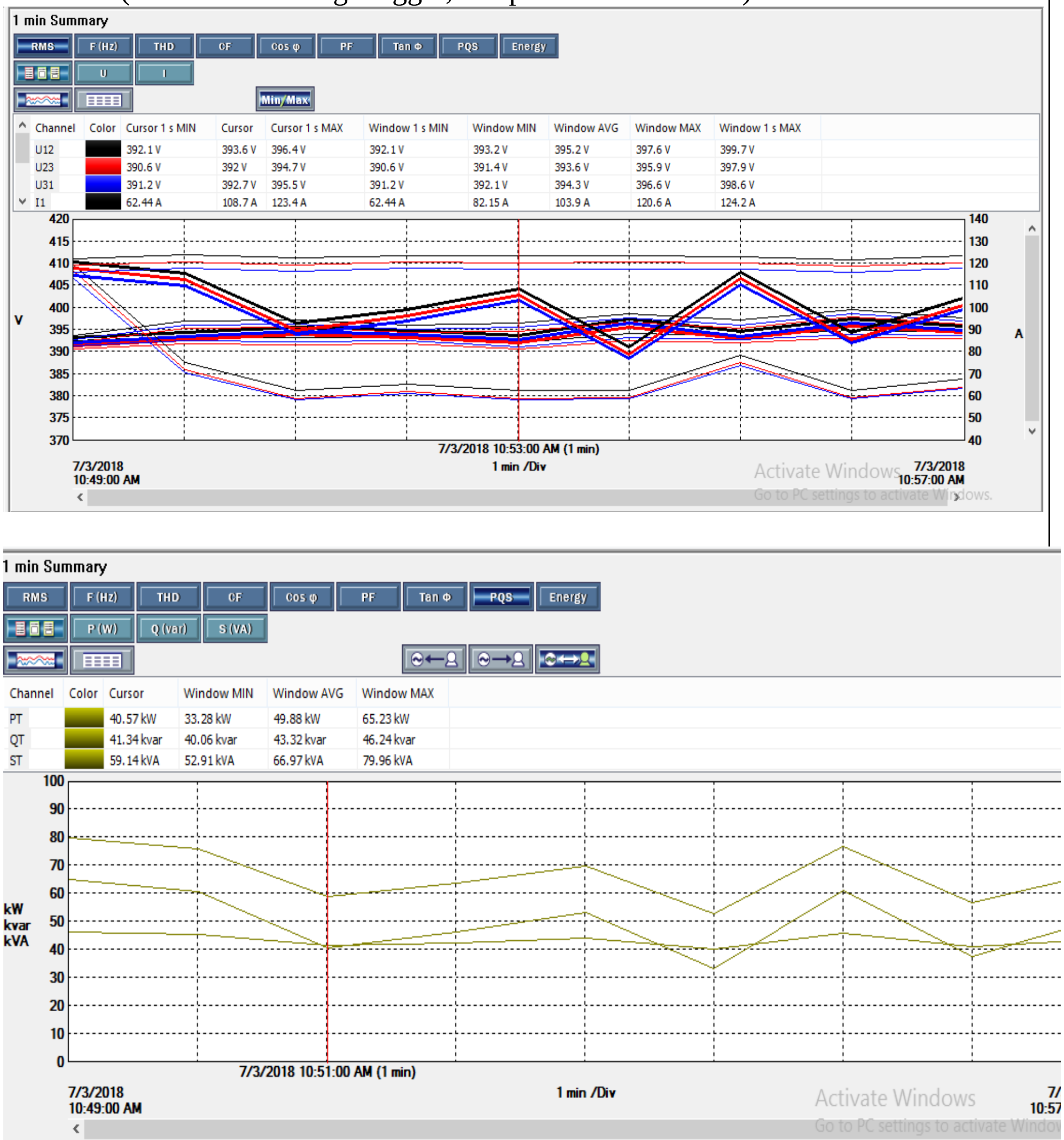


Figure 4.11:Power consumption trends for air compressor GA-808 (2018)

P_1 = Absolute intake pressure kg/ cm^2

P_2 = Absolute delivery pressure kg/ cm^2

Q_f= Free air delivered m^3/hr.

r = Pressure ratio P_2/P_1

$$Isothermal\ power(kW) = \frac{1.017 \times 183 \times 3{,}600 \times log_e\left(\frac{8}{1.017}\right)}{1{,}000 \times 36.7}$$

= **37.65 KW**

$$Isothermal\ efficiency = \frac{37.65}{49.88} \times 100$$

= **75.48%**

$$Free\ Air\ Delivery = \frac{Real\ electrical\ power\ of\ compressor}{install\ shaft\ motor\ power/electrical\ motor\ efficiency}$$

$$install\ Free\ Air\ Delivery\ flow\ rate = \frac{49.88}{75} \times 183$$

= 121.7 L/s

Energy saving opportunity for air compressor

The major opportunity to save energy is in the prevention of leaks in the air compressor system. Leaks were observed as the major cause of wasted energy in the industrial compressed air system. Apart from wasted energy, leaks reduce the efficiency of air operated tools due to pressure drop along pressure lines affecting overall production. Leaks also leads to addition of unnecessary compressor capacity and increase of maintenance cost. The industry needs to perform regular maintenance so as to reduce leakages along the air compressor piping's to less than 10% of compressor output. Leakages and wastages of compressed air in the industry occur mainly at the joints, connections and hoses.

Estimating amount of leakage

The air compressor in the industry uses start and stop controls which makes it easy to estimate the leakage in the system. The method involved starting the system when all pneumatic machines are turned off. The time ‘T’ taken to load and time‘t’ taken to unload was noted. The compressor system will load and unload because the air leaks will cause the system to cycle on and off as the pressure drops due to air escaping from the leaks. The experiment was done 3 times and average computed as presented in table 4.12.

Total leakage percentage is calculated from the equation below

Leakage (%) = [(T x 100)/ (T+t)]

System leakage (L/s) = Q × T / (T + t)

Where,

T = Time on load in seconds

t = Time on unload in seconds

Table 4.11: Leak test of air compressor

	Load pressure(bar)	Load time (T) sec	Unload pressure(bar)	Unload time (t) sec
Cycle 1	6	50	8	49
Cycle 2	6	49	8	50
Cycle 3	6	50	8	49
Average		49.7		49.3

Source: Author’s Compilation, 2018

% Air leakage = T × 100 / (T + t)

= 49.7 × 100 / (49.7 + 49.3)

= **50.20%**

It was observed that significant amount of air is lost along the air distribution system of the compressor. High amount of electricity is consumed to meet air demand by pneumatic machines used in spinning process due to air losses along the pipeline. Fixing air leaks will not only improve the efficiency of the air compressor but will minimize energy consumed by the equipment thus reducing the cost of production.

System leakage (L/s) = Q × T / (T + t)

= 183 × 49.7 / (49.7 + 49.3)

= **91.87 L/s**

Leakage per day, (L/day) = 91.87 ×3600× 16

= 5,291,712 L/day

Specific power for compressed air generation = 65.23/ (183×3600)

= 0.000099 kWh/L

Energy lost due to leakage per day = 0.000099 × 5,291,712

= **523.88 kWh**

$$Energy\ saving\ potential = \frac{523.88 kwh/day}{1{,}043.68 kwh/day}$$

= **50%**

Cost of energy lost per year = 523.88 ×25 days ×12 months ×Ksh 20

= Ksh 3,143,280

Cost of investment fixing leaks (approx) = Ksh 1,000,000

- Pipe cost 800,000
- Labour cost 200,000

Simple payback = investment/savings

= 1,000,000/3,143,280

= 0.3 years or 4 months

The results show huge potential of energy saving through leakage repair. The industry needs to repair air compressor distribution system so as to reduce leakage to less than 10% of the compressor output.

Other energy saving opportunities identified for compressed air systems includes;

- ➢ Regular maintenance program adopted to identify leakage points and repair.
- ➢ All pneumatic operated equipment should be lubricated to reduce friction thus preventing energy wastage due to excessive air consumption.

4.6.5 Motor System

It was observed, based on the findings of the sampled motors (Appendix IX), that the power factor of rewound motors was quite low, as was the percentage of loading. The power factor for the sizing motor was 0.286, and it was operating at 17.1 percent of full load, whereas the power factor for the filter room-1 motor was 0.268, and it was operating at 17.3 percent of full load. Before rewound motors are put to use, it is essential for the industry to make an investment in a portable power and energy logger equipment so that the efficiency of the motors can be evaluated.

It is also important to stress the significance of installing capacitors in order to cut down on losses. A high PF results in an increase in the motor's efficiency as well as a decrease in the losses that are incurred during transmission. Investing in capacitors to increase power factor presents the sector with a clear potential to reduce its overall energy expenses.

Table 4.12: Summary of Energy Saving Opportunities at Rivatex EA Ltd

No.	Opportunity	Potential savings	Potential savings(Ksh/ p.a)	Estimated investment (Ksh)	Simple payback period(p.a)
1	Compressed air system	157,164 kWh/year	3,143,280	2,500,000	0.8
2	Motor retrofit	10,163 kWh/year	161,093	880,000	5.5
3	Steam systems insulation	22,275L/year	1,275,386.40	3,330,000	2.6
4	Lighting systems retrofit	200,457kWh/year	4,009,140	7,927,800	2.0
5	Boiler systems-wood boiler	1,219 ton/year	2,682,900	7,895,000	3.0
	TOTAL		**11,271,799.4**	**22,532,800**	
	Annual fuel cost	Ksh/p.a			
1	Electricity	27,968,690			
2	Wood fuel	4,152,764			
3	Furnace oil	3,600,000			
	Total	**35,721,454**			
	Average monthly	2,976,787			
	% potential savings	**31.6%**			
	Average payback period	**2.0 years**			

CHAPTER FIVE

ENERGY OPTIMIZATION USING A LINEAR PROGRAMMING MODEL

5.1 Introduction

This chapter discusses the production process, the design of a mathematical model, the model parameters, the findings, and discussions, and then draws a conclusion about all of these topics. Also included in this presentation are a sensitivity analysis of the Objective Function Coefficient (OFC) and the Right Hand Side (RHS) value of a constraint.

5.2 Production Process Modelling

The production process is at the heart of any manufacturing business, and as a result, the effectiveness and caliber of the decisions made on the factory floor are a major factor in determining how well the quality management system for the industry functions. The planning of production guarantees an effective and economical deployment of resources in order to complete a manufacturing assignment at the lowest possible cost. Therefore, the availability of the required output of products in type and quantity within the anticipated period at the lowest possible cost is one of the defining characteristics of a production planning process that has been optimized. The purpose of this thesis was to analyze the application of the concept of optimization to production planning with the goal of reducing energy costs while considering a variety of operational restrictions.

Spinning, sizing/preparation, rewinding, weaving, and wet processing are the five primary phases that make up the process of creating textiles (finishing). Each stage is comprised of a collection of machines that serve a variety of distinct functions. The manufacture of textiles begins with the creation of yarn during the spinning step, continues with the production of woven fabric (grey fabric) during the weaving step, and concludes with the wet processing of finished fabric.

Electricity, wood fuel, and oil fuel are the three forms of input energy that are utilized in the textile processing industry. In the first, third, and fourth stages, only electricity is used to run the mechanical devices. However, in the second and fifth stages, electricity is used in addition to fuel (wood and oil) to generate steam and heat from fire-tube boilers and thermo boilers. Figure 5.1 shows the five main stages involved in textile manufacturing, energy inputs and products processed in each stage.

The following is an analysis of each of the five processes in terms of the energy used, the products created, and the technologies utilized.

a) Stage 1-Spinning Process

The initial step in the process of making textiles is called spinning, and it is where the raw ingredients (cotton, viscose, and polyester) are transformed into yarn. The primary components of stage one are the raw ingredients. Yarn, which is the primary product that is treated during stage 1, is depicted as X_1 in the figure that can be found below. Depending on the orders placed by customers or the forecasts of demand provided by the marketing department, a portion of the yarn that is produced in stage 1 is sent to the store as a finished product denoted by P1, while the remaining portion is sent to stage 2 for additional processing.

The process of spinning utilizes a number of machinery, the most important of which are the bale breaker, step cleaner, draw frame, carding machine, and open end machine. The amount of electricity used in the spinning process accounts for 48 percent of the total amount of power used in the plant and is the process that uses the most electricity out of the five that are used in the textile manufacturing industry. In stage 1, the typical amount of power used each month is 43,942 kilowatt hours.

b) Stage 2-Sizing/Preparation

The recycled materials from step 3 are added to the materials that were sent from stage 1 to be used in stage 2. Figure 5 shows the product that was processed in step 2, and it has the symbol X_2. 1. 3 percent of the goods that are processed in stage 2 are transferred to stage 3 as trash for recycling, while the remaining 97 percent of the products are forwarded to stage 4 for additional processing.

The method entails the utilization of wood fuel in a fire-tube boiler to generate steam utilized for size yarn, which is processed with starch solution, and the utilization of power to operate warping machines. The efficiency of the wood fire-tube boiler is 17.35 percent, and the rate of steam output is 3 tons per hour. In stage 2, the typical amount of electricity used each month is 5,400 kW.

c) Stage 3-Rewinding

The recycling unit makes up Stage 3. The X_3 symbol represents the processed waste elements that are then utilized in stage 2, which includes materials from stages 2 and 4. Materials that are discarded are those that remain of the yarn after it has been transferred from the cones to the warpers beam and then from the weavers beam during the weaving process. Electricity is the only resource utilized at this level, and the typical monthly consumption is 4,147 kW.

d) Stage 4-Weaving Process

The fourth stage of the production of textiles is called weaving, and it is during this stage that the yarn that was treated in the previous stage (stage 2) is weaved through weaving machines to generate the grey fabric that is represented by X_4 in figure 5.1. Depending on the orders placed by customers, a portion of the products that are processed during this stage will be sent to the store as finished products represented by P2, while the remaining products will move on to stage 5. Depending on the specific requirements for the grey fabric, the primary weaving machines that are utilized are Projectile, Rapier, Air-Jet, and Water-Jet. Power is the source of energy that stage 4 draws from, and 14,428 kW is the typical amount of electricity consumed each month.

e) Stage 5- Finishing Process (wet processing)

The production process of textiles comes to a close at this stage. The singeing, washing, de-sizing, scouring, bleaching, mercerizing, stentering, curing, and dying procedures are the primary operations that take place during this stage (printing). The grey fabric from step 4 is put through a number of procedures before becoming the final result, which is the finished cloth shown as X_5 in figure 5. 1. Approximately 4% of the items that are processed at this stage are thrown away and are not recycled, whereas 96% of the products that are processed at this level are supplied to stores as finished products represented by P3. Since grey cloth must go through numerous steps in order to fulfill client requests, this final stage also requires a lot of energy. At this stage, there is a high demand for thermal energy, particularly in the washing, dying, treating, and drying of the fabric. This demand is met by the thermo boiler and the fire tube boiler, which are fueled by the combustion of heavy fuel oil and wood fuel, respectively. The machinery, such as the thermostenter, the jigger, and the scouring machine, cannot function without the use of electricity.

With a power output of 1860 kW, the thermo boiler that is being utilized has an efficiency of 86.1 percent. At this point, the typical amount of electricity used in a single month is 20,608 kW.

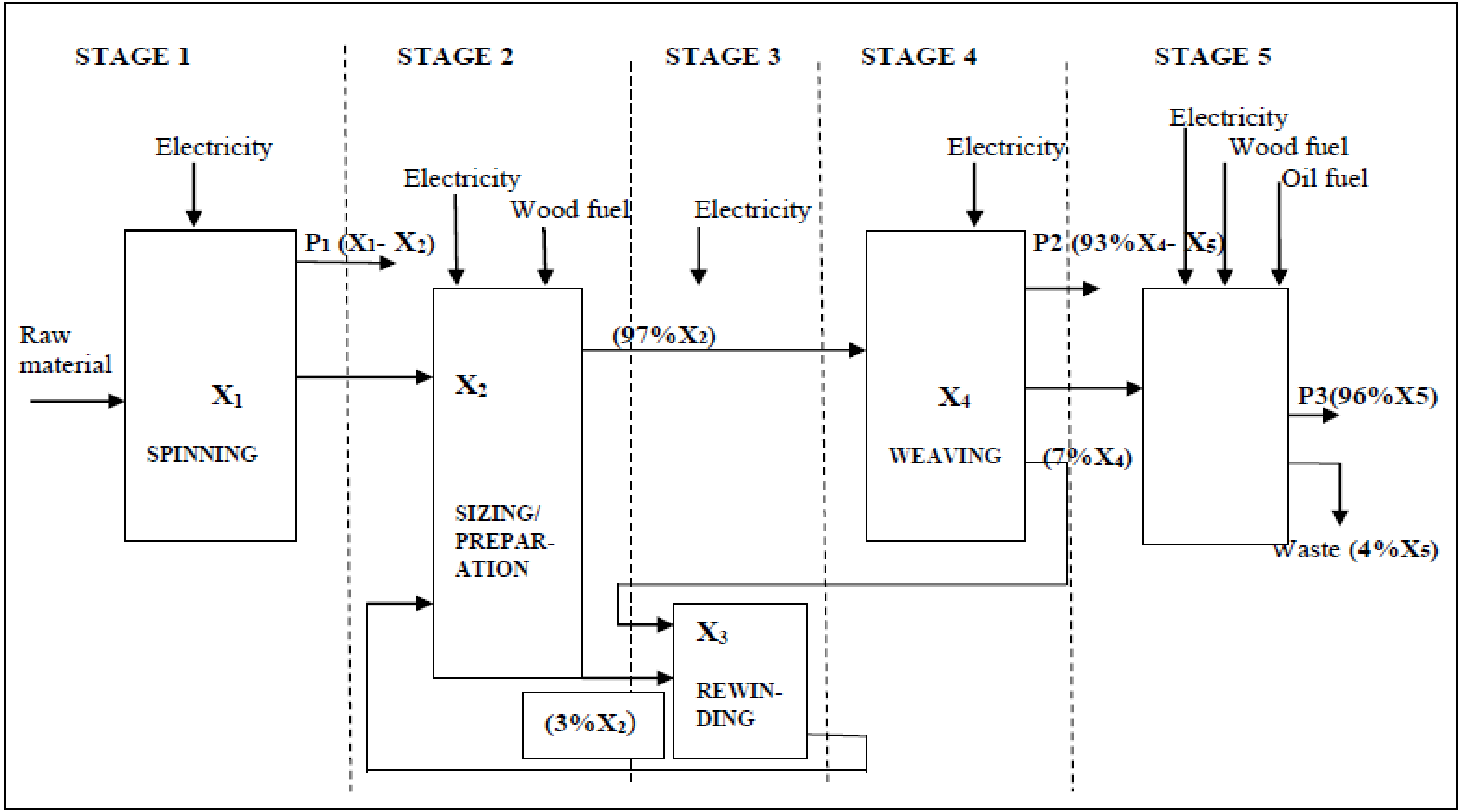


Figure 5.1: Textile Production flow chart

5.3 Formulation of the Mathematical Model

Textile manufacturing is an energy intensive process and the objective of this study was to develop mathematical model that meet the finished products requirements at a minimum cost of energy used in the process subject to different operational constraints. Multi-stage linear programming was used in the development of the model. Material balance equations are the main features of multi-stage linear programming.

Objective Function

The objective function is to minimize the total energy costs.

$$Minimize\ Z = C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 \quad (5.1)$$

Where,

C_1 = Energy cost per unit of product to be produced in spinning

C_2 = Energy cost per unit of product to be produced in sizing/preparation

C_3 = Energy cost per unit of product to be produced in rewinding

C_4 = Energy cost per unit of product to be produced in weaving

C_5= Energy cost per unit of product to be produced in finishing

X_1 = number of units of product processed at stage 1 in a month

X_2 = number of units of product processed at stage 2 in a month

X_3 = number of units of product processed at stage 3 in a month

X_4 = number of units of product processed at stage 4 in a month

X_5 = number of units of product processed at stage 5 in a month

The objective function coefficients are the energy cost (electricity cost, wood fuel cost and oil fuel cost) per unit of product to be produced. These cost coefficients are calculated by multiplying amount of energy used to produce one unit of product by the cost of one unit of energy. Calculated coefficients of energy for the five stages of textile production are presented in table 5.1.

Table 5.1: Energy cost coefficients for the model

Stage	Energy cost per Kg			
	Electricity (Ksh/kg)	Wood fuel(Ksh/kg)	Oil fuel(Ksh/kg)	Total energy cost(Ksh/kg)
Stage 1	50	-	-	**50**
Stage 2	5	2	-	**7**
Stage 3	40	-	-	**40**
Stage 4	15	-	-	**15**
Stage 5	20	14	14	**48**

Note: The electricity cost per kWh is Ksh 20, wood fuel cost per kg is Ksh 2.20 and fuel oil per Litre is Ksh 57 as per company records year 2017.

Material Balance Equations

$P_1 = X_1 - X_2$ (5.2)

$X_3 = 0.07X_4 + 0.03X_2$ (5.3)

$X_4 = 0.97X_2$ (5.4)

$P_2 = 0.93X_4 - X_5$ (5.5)

$P_3 = 0.96X_5$ (5.6)

These constraints are the mathematical forms of the material flows of the process. Constraint (5.2) represents the material flow from stage 1 to finished product P_1 and stage 2. The constraint (5.3) represents the waste material flow from stage 2 and stage 4 to stage 3 to be recycled. Constraint (5.4) represents the material flow from stage 2 to stage 4. Constraint (5.5) represents the material flow from stage 4 to finished product P_2 and stage 5. Constraint (5.6) represents the material flow from stage 5 to finished product P_3.

Demand constraints

$P_1 \geq D_1$ (5.7)

$P_2 \geq D_2$ (5.8)

$P_3 \geq D_3$ (5.9)

$X_1, X_2, X_3, X_4, X_5 \geq 0$ (5.10)

Where;

P_1 = number of units of finished product produced in stage 1 in a month

D_1 = number of units of demand for product produced in stage 1 in a month

P_2 = number of units of finished product produced in stage 4 in a month

D_2 = number of units of demand for product produced in stage 4 in a month

P_3 = number of units of finished product produced in stage 5 in a month

D_3 = number of units of demand for product produced in stage 5 in a month

$P_1 = X_1 - X_2$

$P_2 = 0.93 X_4 - X_5$

$P_3 = 0.96 X_5$

Constraint (5.7, 5.8, and 5.9) ensures that the amount of finished product (P_1, P_2 and P_3) cannot be negative. Constraint (5.10) represents that the amount of products processed in all the stages (X_1, X_2, X_3, X_4, and X5) cannot be negative.

Time constraints

$$P_1t_1 + P_2t_2 + P_3t_3 \leq A \quad (5.11)$$

Where,

t_1= required processing time to produce unit of product P_1

t_2 = required processing time to produce unit of product P_2

t_3 = required processing time to produce unit of product P_3

A = available processing time in a month

Constraint (5.11) ensures that total production time in a month cannot exceed the available processing time in a month. Table 5.2 shows production rate of each product and the required processing time to produce one unit of product.

Table 5.2: Production rate (kg/hr) and processing time per unit product (hr/kg)

Product	**Production rate(kg/hr)**	**Processing time per unit product(hr/kg) 1/production rate**
Product, P_1-yarn	150	0.007
Product, P_2-grey fabric	75	0.013
Product, P_3-finished fabric	50	0.02

5.4 Model Parameters

The necessary data include;

(i) Monthly energy consumption (electricity, wood fuel and oil fuel) for each stage.

(ii) Monthly production for each stage

(iii) Forecast for future monthly demands

(iv) Capacity of the process

(v) Material availability

The data required were obtained during investigation of energy use from historical records, production process and production manager data. The necessary input data for the model are mainly the energy (electricity, wood fuel and oil fuel) used per unit of each product at each stage. The units of energy used are kWh, litre and Kg for electricity, oil fuel and wood fuel respectively.

5.5 Linear Program Solver

Linear Program Solver (LiPS v1.11.1 software) was used to solve the energy problem. This program solved the linear program problem and gave the ranges over which the cost coefficients and the right-hand side variables can vary without changing the optimality or feasibility of the problem. Parameters used in the model for the case study energy problem formulation have been assumed basically to remain constant throughout the year.

Input Data

Minimize total cost (Z) = $C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5$

Minimize Z = $50X_1 + 7X_2 + 40X_3 + 15X_4 + 48X_5$

Subject to;

	$0.03X_2$	$-X_3$	$0.07X_4$		=	0
	$0.97X_2$		$-X_4$		=	0
X_1	$-X_2$				≥	D_1
			$0.93X_4$	$-X_5$	≥	D_2
				$0.96X_5$	≥	D_3
$0.007X_1$	$-0.007X_2$		$0.013X_4$	$0.0062X_5$	≤	A
X_1,X_2,X_3,X_4,X_5					≥	0

D_1= Product, P_1 monthly demand

D_2= Product, P_2 monthly demand

D_3= Product, P_3 monthly demand

A = Available processing time in a month

The monthly production demands in Kg for the three products and available processing time in a month are given below;

P_1 = 400 kg, P_2 = 600 kg, P_3 = 20,000 kg, A = 720 hrs

OUTPUT OF THE MODEL

The model consists of 5 variables and 11 constraints. The minimum cost of product mix, when the electricity cost is Ksh 20/kWh, wood fuel cost Ksh 2.20/kg and fuel oil is Ksh 57/litre, is Ksh 2,813,030 for the planned month.

```
>> Optimal solution FOUND
>> INFO: feasible solution FOUND after 5 iterations
>> INFO: LiPS finished after 5 iterations and 0.03 seconds
>> Minimum energy cost (Z) = Ksh 2,813,030 per month
```

Table 5.3: Output of the model variable and constraint

Variable (X_n)	Value (kg)	Obj.Cost,C_n(Ksh/kg)	Reduced Cost
X1	24159.4	50	0
X2	23759.4	7	0
X3	2326.04	40	0
X4	23046.6	15	0
X5	20833.3	48	0

CONSTRAINTS

Constraint	Value	RHS	Dual Price
Row1	400	400	50
Row2	0	0	-40
Row3	0	0	60
Row4	600	600	7780/93
Row5	20000	20000	137.142
Row6	431.572	720	0
Row7	24159.4	0	0
Row8	23759.4	0	0
Row9	2326.04	0	0
Row10	23046.6	0	0
Row11	20833.3	0	0

Table 5.3 shows that to produce 20,000 kg of finished fabric, 400kg of yarn and 600 kg of woven fabric as finished products, it requires the use of 24,159.4 kg of yarn to be produced in spinning to satisfy the entire process. The model allocates resources optimally starting from spinning to finishing process. Production of textile products in excess leads to wastage of raw materials and also wastage of energy consumed during processing the wasted products. The model also indicates the required time in producing the products demanded for planning purposes to be 432 hours. Results of the model provide optimum production mix with minimum energy cost.

5.6 Sensitivity Analysis

Sensitivity analysis deals with finding out the amount by which we can change the input data for the output of our linear programming model to remain comparatively unchanged. Sensitivity analysis is therefore the study of how sensitive solutions are to parameter changes. This helps us in determining the sensitivity of the data we supply for the problem.

This includes analyzing changes in:

(i) An Objective Function Coefficient (OFC)

(ii) A Right Hand Side (RHS) value of a constraint

The sensitivity analysis for the monthly demand variables is shown in table 5.4 while sensitivity analysis for cost coefficients is shown in table 5.5.

Table 5.4: Sensitivity analysis RHS range

Constraint	Current RHS	Min RHS	Max RHS	Dual Price
Row1	400	-23759.4	41603.9	50
Row2	0	-infinity	2326.04	-40
Row3	0	-23046.6	+infinity	60
Row4	600	-20833.3	21233.7	7780/93
Row5	20000	0	33722.1	137.142
Row6	720	431.572	+infinity	0
Row7	0	-infinity	24159.4	0
Row8	0	-infinity	23759.4	0
Row9	0	-infinity	2326.04	0
Row10	0	-infinity	23046.6	0
Row11	0	-infinity	20833.3	0

Table 5.4 lists the range of values for which the RHS (monthly production demand variables) may change without changing the optimality of the solution. Dual price is the amount in Kenya shillings per month by which the objective function is increased

per unit increase of the corresponding right hand side value (monthly production demand, Kg/Month). Table 5.5 lists the range of values for which the costs of the various energy sources may vary without changing the optimality of the solution. Reduced cost coefficients indicate how much each cost coefficient would have to be reduced before the activity represented by the corresponding variable would be cost-effective.

Table 5.5: Sensitivity analysis cost range

Variable, X_n	Current COST, C_n	Min COST	Max COST	Reduced Cost
X1	50	0	+infinity	0
X2	7	-68.466	+infinity	0
X3	40	-730.848	+infinity	0
X4	15	-62.8	+infinity	0
X5	48	-7780/93	+infinity	0

5.7 Summary

In this research, a plant using electricity, wood fuel and oil fuel for production was considered for energy optimization. Linear programming model has been developed which minimizes total energy cost while meeting monthly production demands. Minimum energy cost for the planned monthly production was found to be Ksh 2,813,030. The model presented in this research lends an understanding to the complex manufacturing system problem and presents a straight forward method for its solution. Results of the case study will improve the quality of decision making process. The production management team will become more objective than subjective. The system of equations can be expanded or reduced to accommodate any variety of system combinations.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Energy utilization evaluation in Rivatex East Africa Ltd found that high energy consumption occurs in spinning process (48%) followed by weaving process (26%) and wet processing (22%). Also, specific energy consumption for spinning process, weaving process and wet process was found to be 3.4 Kwh/Kg, 1.2 Kwh/Kg and 1.05 Kwh/Kg respectively which is high compared to textile industries in developed countries. This shows that adopting energy efficiency measures would bring down the cost of energy utilized in the plant.

A thorough performance evaluation of various utility systems showed that motor system, air compressor, lighting system, steam distribution system and boiler system are the main energy intensive systems which have great potential for energy saving amounting to 31.6%. Also, the average simple payback period for the investments was found to be 2 years. This implies that improvement of energy efficiency of the energy intensive utility system reduces the costs of energy incurred by the plant by 31.6% which is substantial to make products manufactured competitive in local and global markets.

Energy saving and conservation measures were identified for various energy intensive utility systems. For steam systems, leakages and poor insulation of steam distribution systems are the main causes of inefficiency. The high temperature and pressure drop along steam pipes affects the performance of end user equipment. Lack of insulation on steel pipes from thermo boiler is the root cause of heat losses despite the fact that insulation materials are cheap and falls on low cost investment with high returns.

For boiler systems flue gas losses and poor insulation are the main causes of poor performance of wood fire- tube boiler. Also poor storage of firewood increases moisture content which lowers the efficiency of the boiler. Regular cleaning of boiler tubes is necessary to prevent fouling which reduces heat transfer from the flue gases to water outside the fire tubes. Fouling of boiler tubes is detected by the high flue gas temperature due to poor heat transfer.

For motor systems rewinding is the major cause of poor motor efficiency. All rewinded motors should be tested to confirm their efficiency. If the efficiency falls below 60% it is recommended to replace with a new efficient motor. A number of energy saving opportunities identified in this study are low cost investment with high returns that can be adopted in the existing systems. Some of these low cost investments with short payback periods include fixing leakages both in air compressor and steam distribution systems, insulation of bare pipes and a shade for proper storage of firewood. The high cost capital intensive measures with high returns may be subject to further detailed investigation and analysis though the results of the study should be used as a basis for future research on energy saving opportunities.

Finally, energy model to optimize the energy utilization in the plant was developed. The displayed yearly energy cost reduction of 5.5% leading to savings of Kshs. 2 million per year. If energy saving measures identified are adopted to reduce energy consumption in the textile industry, production cost will reduce thus improving its competitiveness and profitability.

6.2 Recommendation

Assessment of energy utilization and saving opportunities in textile industry has been analyzed in this research. The research focused on detailed analysis on energy use by equipment and different processes in textile industry such as spinning, weaving and wet processing and identified energy saving opportunities to be implemented to reduce energy use without affecting production.

Based on this research, the following recommendations will help reduce energy wastages and the rising energy consumption which affects greatly the competitiveness of local textile industry through increased cost of production.

Develop effective energy management system (EnMS) to manage energy use in the industry. The energy management framework provided in ISO 50001(energy management system standard) should be implemented through the appointment of energy manager. Energy manager responsibilities include implementation of energy policies, setting targets, monitoring energy consumption and energy budgets. It is through energy management system that industries are able to systematically track, analyze and plan their energy use thus enabling greater control of energy performance as well as operational performance. EnMS benefits include early detection of leaks, effective use of waste heat and electricity or fuel consumption forecasts.

Increase awareness of energy matters through training of employees. The understanding of benefits accompanying prudent energy use changes employee’s attitudes to be more responsible. Skilled and knowledgeable employees ensure efficient use of energy resources and systems with little or no supervision. The energy management team should incorporate employees in developing energy conservation initiatives for them to take ownership.

The government should increase financial support for the industry to continue phasing out outdated technologies and adopting new energy efficient technologies. Outdated technologies tend to consume more energy with less production and in some cases poor quality of products which affects greatly competitiveness of the industry locally and internationally. Adoption of waste heat recovery unit technology (economizer) to recover waste heat found in flue gas will add to the efficiency of the process and thus decrease the costs of fuel and energy consumption needed for that process

The industry should utilize the use of transparent sheets on the roof and skylights to reduce the use of artificial lighting during the day. Also, the adoption of renewable energy resources should be incorporated to reduce energy cost for the industry. Lighting costs can be reduced with the use of solar energy which is clean source of energy. Apart from lighting buildings solar energy can be used for street lighting and boiler feed water heating.

The industry should invest on portable instruments such as power and energy logger, flue gas analyzer and lux meter. These instruments help to monitor the performance of high energy consuming equipment on regular basis.
Though this research focused on Rivatex East Africa Ltd, further studies should be conducted in other textile industries to assess energy utilization and to identify energy saving and conservation measures that exist.

Despite the fact that the research focused on energy saving opportunities in textile industry specifically Rivatex East Africa Ltd being one of the largest textile industries in Kenya, the opportunities identified applies to other similar industries.

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APPENDIX

Appendix I: Electricity Cost in Kenya

PUBLIC NOTICE

erc.
Energy Regulatory Commission

CLARIFICATION ON THE RETAIL ELECTRICITY TARIFF REVIEW FOR THE 2018/19 TARIFF CONTROL PERIOD (TCP)

Following the concerns raised by the media and the public on social media platforms regarding the new retail electricity tariffs that came into effect on 1st August 2018 for the prepaid customers and 1st July 2018 for the postpaid customers, the Energy Regulatory Commission (ERC) wishes to make the following clarifications on the impact of the new tariffs on consumer power bills;

a) The average retail tariff inclusive of taxes and levies reduces from 23.49 KShs/kWh to 20.18 KShs/kWh representing an overall reduction of 14.1%.

b) The retail tariffs for the Domestic Consumer category has been restructured into two distinct categories.
i) Domestic Consumer-Lifeline category: The threshold for the lifeline category has been reduced from 50kWh to 10kWh per month. This will benefit the 3.4Million low income households who consume less than 10kWh in a month.

ii) Domestic Consumer-Ordinary category: There will be an increase in tariff for customers consuming up-to 1000kWh in a month. Those who consume more will get a reduction in the overall bill.

c) Fixed charge, which has hitherto featured in the power bill, has been eliminated and therefore, prepaid customers will now consistently receive the same number of units for a given amount of money in a particular month.

d) The base year for determination of the Forex and Inflation Adjustments has been revised to March 2017 hence there will be minimal adjustments monthly.

The following is a summary of the impact of the new tariffs to the different customer categories.

Table 1: *Summary of Impact for each Customer Category:*

Customer Category	Current Tariffs (July 2018)Bill KShs/kWh	Approved Tariffs (August 2018) Bill KShs/kWh	Change in Tariff KShs/kWh	Change in Tariff %
Commercial Industrial 1	21.74	20.71	(1.02)	-4.70%
Commercial Industrial 2	18.77	17.92	(0.85)	-4.55%
Commercial Industrial 3	17.60	16.88	(0.72)	-4.11%
Domestic Lifeline (2kWh)	97.44	17.59	(79.84)	-81.95%
Domestic Lifeline (1kWh)	184.44	17.59	(166.84)	-90.46%
Domestic Ordinary (11-100kWh)	18.38	22.19	3.81	20.75%
Domestic Ordinary (300kWh)	21.35	22.19	0.84	3.93%
Domestic Ordinary (500kWh)	21.95	22.19	0.24	1.11%
Domestic Ordinary (1000kWh)	22.39	22.19	(0.20)	-0.90%
Domestic Ordinary (2000kWh)	24.98	22.19	(2.79)	-11.17%
Domestic Ordinary (5000kWh)	29.37	22.19	(7.18)	-24.45%
Average Retail Tariff	**23.49**	**20.18**	**(3.31)**	**-14.1%**

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Energy Regulatory Commission
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Appendix II: Values Used

Cost of 1kwh = Ksh 20

Cost of 1 liter of oil= Ksh 57

Cost of 1 tone of wood fuel = Ksh 2,200

Appendix III: Fuel Data For Combustion With Air

Isidoro Martínez

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FUEL DATA FOR COMBUSTION WITH AIR

Fuel	Formula (state)	Density [kg/m³]	Theoretical air/fuel ratio	Higher Heating Value [MJ/kg]	Maximum adiabatic combustion temp. K	Flash point &Autoignition temperature[c] [K]	Ignition limits[b]	Maximum laminar deflagration speed [m/s]
Acetylene	C_2H_2(g)	1.1	11.9 m³/m³	48	2500[a]	<180, 600	2.5..100	1
Benzene	C_6H_6(l)	880	13.3 kg/kg	42.3	2400	262, 840	1.5..7.5	1
Bio-diesel	$C_{17}H_{32}O_2$(l) esters	880	12.4 kg/kg	40	-	420, -		
Bio-petrol	$C_6H_{14}O$(l) Ethyl Tert. Butyl Ether	750	12.2 kg/kg	36	-	-		
n-Butane	C_4H_{10}(g)	2.4	31 m³/m³	49.5	2250	210, 670	1.5..9.3	0.4 (cut off)
iso-Butane	C_4H_{10}(g)	2.4	31 m³/m³	49.5	2250	190, 710	1.6..8.4	0.4 (cut off)
Carbon (graphite)	C(s)	2250	11.5 kg/kg	33		600, 670		
Carbon monoxide	CO(g)	1.2	2.4 m³/m³	10	2400	-, 900	12..75	0.[illegible] (cut off)
Coal (dry, mean)	85%C5%H5%O5%M(s)[c]	1300..1400	10 kg/kg	31	2200	550, 600		
Diesel or Gas-oil	87%C13%H(l)[d]	820..860	15 kg/kg	47		330, 480	0.6..8	
DME	C_2H_6O(g) (dimethyl ether)	1.8	14.3 m³/m³	30		232, 600	3.4..20	0.4 (cut off)
ETBE	$C_6H_{14}O$(l) (ethyl tert-butyl ether)	770	12.2 kg/kg	43		248, 580	1.4..10	
Ethane	C_2H_6(g)	1.2	16.7 m³/m³	51.9	2100	140, 800	3.0..15	0.4 (cut off)
Ethanol	C_2H_6O(l)	790	9.0 kg/kg	29.7	2200	285, 630	3.3..21	0.8 (cut off)
Ether	$C_4H_{10}O$(l) (diethyl ether)	715	11.2 kg/kg	37.2		230, 440	1.8..37	
Fuel-oil	84%C10%H3%S1%N2%H2O(l)[e]	850..990	15 kg/kg	44	2200	320, 480	0.7..5	
Gasoline	85%C15%H(l)[f]	730..760	14.7 kg/kg	48	2200	230, 650	1.3..8	0.3 (cut off)
n-Hexadecane	$C_{16}H_{34}$(l)	773	14.9 kg/kg	47.3	2200	400, 475	0.5..4.7	
n-Heptane	C_7H_{16}(l)	685	15.2 kg/kg	48.1	2200	269, 560	1.1..6.7	0.4 (cut off)
Hydrogen	H_2(g)	0.08	2.4 m³/m³	142	2400	-, 850	4.0..75 (cut off)	
Kerosene Jet A-1	85%C15%H(l)[g]	780..840	15 kg/kg	47	2300	330, 500	0.7..6 (cut off)	
Methane	CH_4(g)	0.67	9.5 m³/m³	55.5	2200	85, 850	4.5..16 (cut off)	
Methanol	CH_4O(l)	790	6.5 kg/kg	22.7	2150	285, 680	6.0..37 (cut off)	
Natural gas	CH_4(g)[h]	0.68..0.70	9.5 m³/m³	54	2250	-, 850	5.3..15 (cut off)	
n-Octane	C_8H_{18}(l)	703	15 kg/kg	47.9	2300	286, 500	1..6 (cut off)	
iso-Octane	C_8H_{18}(l)[i]	690	15 kg/kg	47.9	2300	261, 690	1..6 (cut off)	
Propane	C_3H_8(g)	1.8	23.8 m³/m³	50.0	2250	170, 750	2.0..9.5 (cut off)	
Propylene	C_3H_6(g)	1.8	21.4 m³/m³	48.9	-		2.4..11 (cut off)	
Wood (dry, mean)	50%C5%H45%O(s)[j]	500..1000	5.6 kg/kg	20	2100	550, 700		

All data for combustion with air, at 298 K and 100 kPa.
[a]Maximum adiabatic combustion temperature for the oxyacetylene torch 3400 K.
[c]Flash point: minimum temperature for spark ignition near the condensed phase. Autoignition: minimum temperature for self ignition (without spark).
[b]% by volume of gaseous fuel in the mixture with air.
[c]% by weight, dry bituminous coal; C refers to total carbon content (fixed plus volatile matter), M refers to inert matter.
[d]% by weight; diesel or gas-oil is a distilled mixture with M=0.17..0.20 kg/mol, T_b=470..550 K (10% and 90% boiled), p_v(38 °C)=0.7 kPa, ν=4·10⁻⁶ m²/s at 55 °C (the f… diesel), 50..55 cetane number, and sulfur content <500 ppm, that may be approximated by $C_{12}H_{26}$ (n-Dodecane). Cetane is n-hexadecane, $C_{16}H_{34}$. As for most hydrocar… water is negligible, and it may be carcinogen.
[e]% by weight; fuel-oils are mixtures of residues and heavy fraction distillates (and maybe used and waste oils), with sulfur content <0.5%, and may be approximated by… usually below 0 °C for distillates and below 20 °C for residuals, but they are heated for handling.
[f]% by weight; gasoline is a distilled mixture with M=0.10..0.12 kg/mol, T_b=300..440 K (10% and 90% boiled), p_v(38 °C)=60 kPa for the summer blend and p_v(40 °C)=… blend, 90..100 motor octane number, and sulfur content <300 ppm, that may be approximated by C_7H_{17} or C_8H_{18} (iso-octane), except for the vapour pressure. Composit… wide scatter in property values; e.g. the flash point may range from -250 K to 240 K, autoignition temperature from 550 K to 750 K.
[g]% by weight; kerosene (or kerosine) is a distilled mixture with T_b=450..600 K (10% and 90% boiled), T_f=−40 °C, ν=8×10⁻⁶ m²/s at −20 °C, that may be approximated … or 1-dodecene ($C_{12}H_{24}$). Commercial (Jet A-1, Jet A, and Jet B) and military (JP-4, JP-5, JP-8...) jet propulsion fuels, are basically mixtures of kerosene and gasoline (fr… 99.5% kerosene for JP-5 and JP-8, 100% kerosene for Jet A-1), plus special additives (1..2%): corrosion inhibitors, anti-icing, and anti-static compounds. Jet A-1 is the … T_f=−50 °C (-47 °C as a limit); Jet A (with T_f=−40 °C) is a low-grade Jet A-1 only and mostly used in USA; and Jet B (T_f<−50 °C), the commercial name of JP-4, is only … climates. They all have a lower heating value of 42.8..43.6 MJ/kg. Minimum flash point is 60 °C for JP-5, 38 °C for Jet A-1 and JP-8 (Jet A-1 typical value is 50 °C, wit… this point of 1.5 kPa; 1 kPa at 38 °C), and -20 °C for JP-4. Typical density at 15 °C is 810 kg/m³ for Jet A-1, and 760 kg/m³ for Jet B.
[h]Natural gas is a mixture with some 90% methane, M=0.017..0.019 kg/mol, T_b=110..120 K (10% and 90% boiled) and 120 motor octane number.
[i]Isooctane or trimethylpentane, T_f=166 K, T_b=372 K, c=2200 J/(kg·K), Motor Octane Number MON=100.
[j]% by weight; wood is basically cellulose, a long polysaccharide [illegible], with n=5000..10000 and M=500..10000 kg/mol.

Source: Isidoro Martinez, 1995-2018

Appendix IV: Price List of Capacitors

Capacitor rating(Kvar)	**unit cost(Ksh)**
6.3	10,000
12.5	20,000
20	25,000
25	30,000
50	60,000
100	200,000

Appendix V: Typical Heat Transfer Coefficients

Overall Heat Transfer Coefficient Table Chart Various Fluids (Liquids and Gasses)

Conditions of heat transfer	W/(m^2K)
Gases in free convection	5–37
Water in free convection	100–1200
Oil under free convection	50–350
Gas flow in tubes and between tubes	10–350
Water flowing in tubes	500–1200
Oil flowing in tubes	300–1700
Molten metals flowing in tubes	2000–45000
Water nucleate boiling	2000–45000
Water film boiling	100–300
Film-type condensation of water vapor	4000–17000
Dropsize condensation of water vapor	30000–140000
Condensation of organic liquids	500–2300

https://www.engineersedge.com/thermodynamics/overall_heat_transfer-table.htm

Appendix VI: Power Factor and Demand Charges in Kenya

THE KENYA POWER & LIGHTING CO. LTD.
NEW POWER TARIFFS

This is to advise the General Public that from 1st July 2008, the Electricity Tariffs have been revised upwards as shown in the three tables below.

There are now five main consumer categories: Domestic, Small Commercial, Interruptible, Street lighting and Commercial/Industrial. AO tariff is now Domestic Consumers (DC), A1 is Small Commercial (SC), DO is Interruptible (IT), EO is Street Lighting (SL).

NEW TARIFFS FOR DC, SC IT AND SL CUSTOMERS						OLD TARIFFS FOR AO, A1, DO AND EO CUSTOMERS				
Tariff	Voltage	Consumption per month	Fixed charge	Consumption per month	New Cost per kWh	Old Tariff	Old Fixed charge	Old Consumption per month	Old Cost per kWh	% increase
Domestic Consumers (DC)	240V or 415V	<=15,000 kWh	KShs.120.00	0-50kWh 51-1500kWh > 1,500 kWh	KShs.2.00 KShs.8.10 KShs.18.57	Method AO	KShs.75.00	0-50kWh 51-300kWh 301-3000kWh 3001-7000kWh	KShs.1.55 KShs.6.65 KShs.7.00 KShs.13.80	29.03 21.8
Small Commercial (SC)	240V or 415V	<=15,000 kWh	KShs.120.00		KShs.8.96	Method A1	KShs.150	<=7000 kWh	KShs.6.70	33.73
Interruptible (IT)	off-peak metered at 240V or 415V	<=15,000 kWh	KShs.120.00 KShs.240.00 when used with DC or SC		KShs.4.85	Method DO	KShs.150.00	=<7000 kWh	KShs.4.95	-2.02
Street Lighting (SL)	metered at 240V		KShs.120.00	240V or 415V	KShs.7.50	Method EO	KShs.250.00	=<7000 kWh	KShs.6.20	20.96

The industrial tariffs BO, B1, B2, B3, C1, C2, C3, C4 and C5 have been merged into the Commercial / Industrial tariff as shown in the tables below.

OLD TARIFFS - COMMERCIAL/INDUSTRIAL CUSTOMERS									
Tariff/ Charges	BO	BI	B2	B3	C1	C2	C3	C4	C5
Fixed Charge	800.00	600.00	2,000.00	7,500.00	600.00	2,000.00	7,500.00	7,500.00	7,500.00
Voltage	415 V	240/415 V	11 kV	66/132 kV	415 V	11/33 kV	66/132 kV	66/132 kV	66/132 kV
Charge Per unit (kWh)	6.40	5.16	4.60	4.40	5.10	4.40	4.17	4.07	4.00
Demand (KShs. Per KVA)	-	300.00	200.00	100.00	300.00	200.00	100.00	80.00	80.00
Units Consumed	7,000 - 100,000	7,000 - 100,000	7,000 - 100,000	7,000 - 100,000	100,001 - 5,000,000	100,001 - 5,000,000	100,001 - 5,000,000	5,000,001 - 7,5000,000	> 7,5000,000

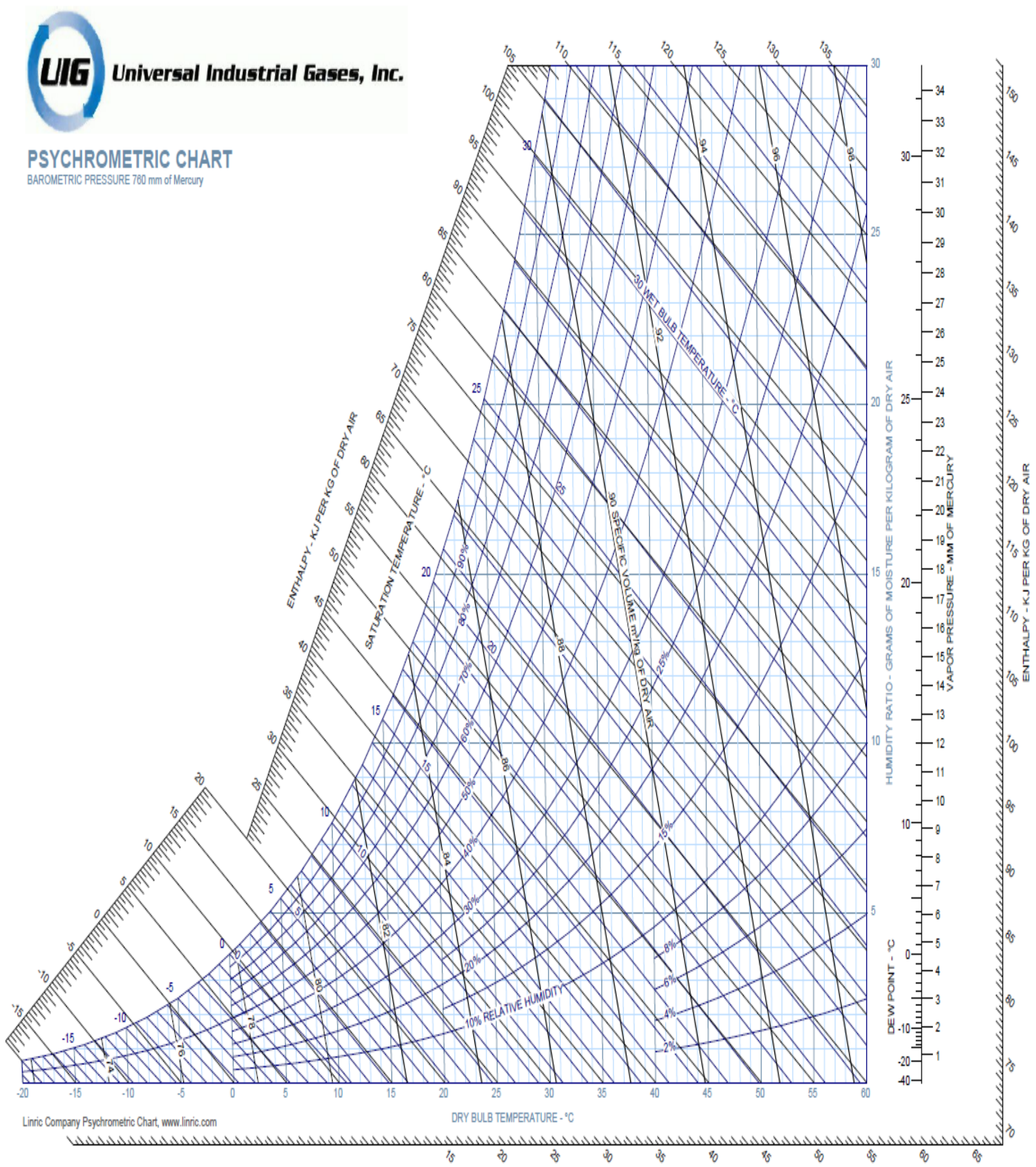
NEW TARIFFS - COMMERCIAL/INDUSTRIAL CUSTOMERS					
Tariff/ Charges	CI	CI2	CI3	CI4	CI5
Fixed Charge	800.00	2,500.00	2,900.00	4,200.00	11,000.00
Voltage	415 V	11 kV	33/40 kV	66 kV	132 kV
Charge Per unit (kWh)	5.75	4.73	4.49	4.25	4.10
Demand (KShs. Per KVA)	600.00	400.00	200.00	170.00	170.00
Units Consumed	> 15,000	> 15,000	> 15,000	> 15,000	> 15,000

All government taxes and other levies remain unchanged as follows:

- Fuel Oil Surcharge [FOS] which fluctuates every month due to increase/decrease in the price of fuel used in power generation.
- Foreign Exchange Rate Fluctuation Adjustment [FOREX].
- VAT at 16% of standing charge and taxable value of electricity energy consumed with the exemption of the first 200Units under domestic consumption.
- Rural Electrification Programme [REP] Levy at 5% or Revenue from unit sales.
- Energy Regulatory Commission [ERC] Levy at cents 3/kWh.
- Power Factor surcharge for any installation whose power factor is less than 0.9 lagging.

The Kenya Power & Lighting Co. Ltd.

Appendix VII: Psychrometric Chart



Appendix VIII: Statistical Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.782244
R Square	0.611906
Adjusted R	0.573096
Standard E	7341.8
Observatio	12

ANOVA

	df	SS	MS	F	ignificance F
Regression	1	8.5E+08	8.5E+08	15.76692	0.00264
Residual	10	5.39E+08	53902023		
Total	11	1.39E+09			

	Coefficients	andard Erro	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	Jpper 95.0%
Intercept	22406.46	5822.855	3.848019	0.003223	9432.329	35380.59	9432.329	35380.59
X Variable :	1.099193	0.276822	3.970758	0.00264	0.482395	1.715991	0.482395	1.715991

Figure 8.1 Relationship between production and energy consumption in spinning process

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.708245
R Square	0.501611
Adjusted R	0.451772
Standard E	3863.79
Observatio	12

ANOVA

	df	SS	MS	F	ignificance F
Regression	1	1.5E+08	1.5E+08	10.06464	0.009946
Residual	10	1.49E+08	14928875		
Total	11	3E+08			

	Coefficients	andard Erro	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	Jpper 95.0%
Intercept	9981.076	4549.867	2.193707	0.053002	-156.66	20118.81	-156.66	20118.81
X Variable :	0.70967	0.223696	3.172482	0.009946	0.211245	1.208095	0.211245	1.208095

Figure 8.2 Relationship between production and energy consumption in weaving process

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.636928
R Square	0.405677
Adjusted R	0.346245
Standard E	4539.222
Observatio	12

ANOVA

	df	SS	MS	F	ignificance F
Regression	1	1.41E+08	1.41E+08	6.825865	0.025923
Residual	10	2.06E+08	20604537		
Total	11	3.47E+08			

	Coefficients	andard Erro	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	Jpper 95.0%
Intercept	11014.88	3898.745	2.825239	0.017998	2327.94	19701.83	2327.94	19701.83
X Variable :	0.440433	0.168578	2.612636	0.025923	0.064818	0.816049	0.064818	0.816049

Figure 8.3 Relationship between production and energy consumption in wet processing

Appendix IX: Motor Load Assessment

1. Air compressor motor

Table 8.1 Air compressor motor nameplate and measured parameters

	Nameplate parameters	Measured parameters
Current(A)	140/154	101
Voltage(V)	380/415	394
Rated power(KW)	75	49.88
Rpm	1485	1485
Cos φ	0.86	0.724
FREQUENCY(HZ)	50	50

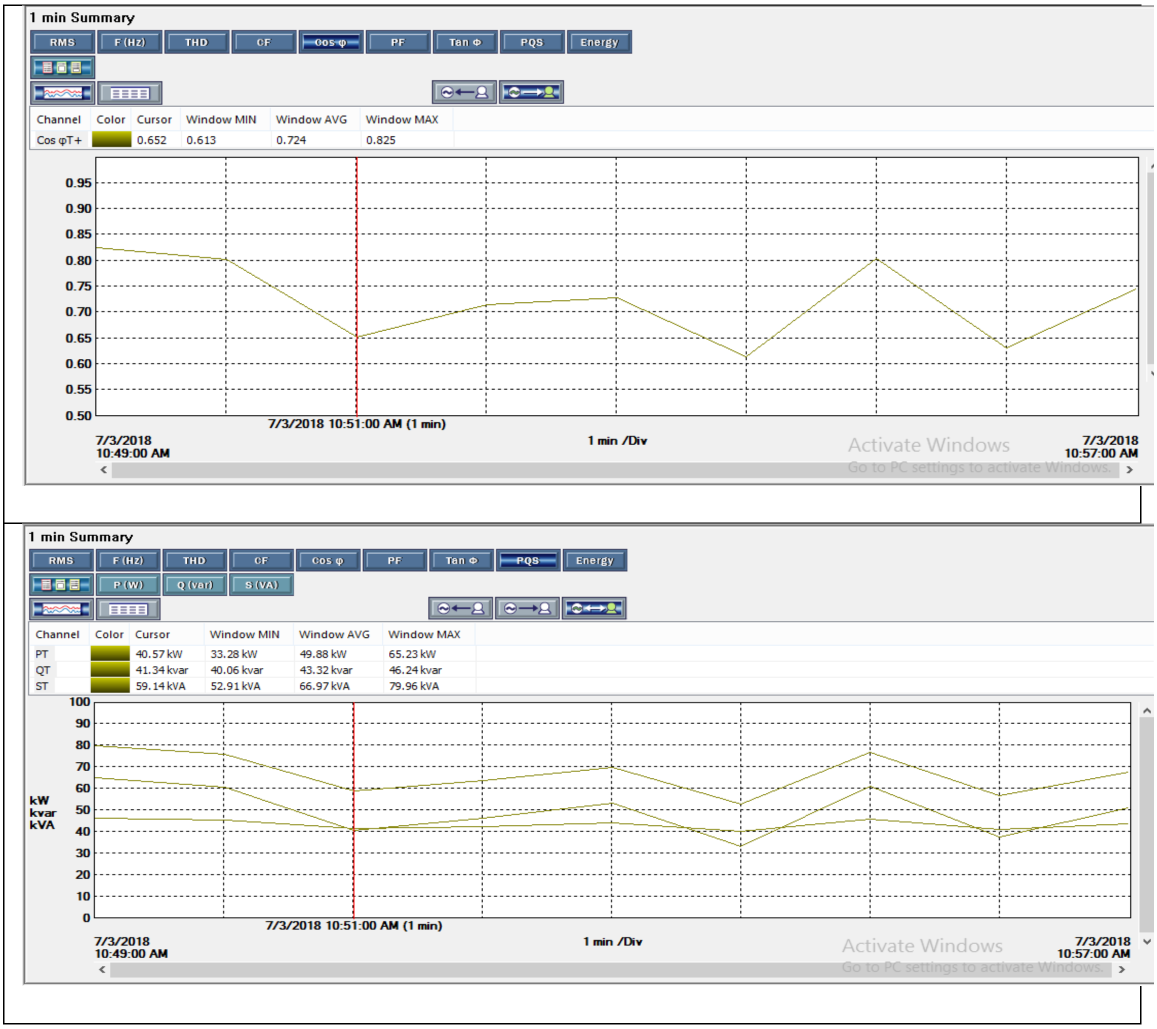


Figure 8.4: Power trends and power factor profile for air compressor motor

Table 8.2 Power factor correction from0.724 to 0.90 for air compressor motor

Existing situation	
Active power P	49.88kW
% of full load	66.5%
Exiting power factor (cos φ_1) φ_1=43.6	0.724
Resulting apparent power S_1: $S_1 = \frac{P}{cos_{ö1}} S_1 = \frac{49.88}{0.724}$	68.9kVA
Improved situation	
Target power factor (cos φ_2)[1] φ_2=25.8	0.90
Required capacitor rating Q_C: Q_C= P ×(tan φ_1-tan φ_2) = 49.88×(tan 43.6 -tan 25.8)	23.38kVA
Apparent power S_2: $S_2 = \frac{P}{cos_{ö2}} S_2 = \frac{49.88}{0.9}$	55.42kVA
Potential savings pa= (S_1-S_2)×Demand charge Ksh 520×12 months = (68.9-55.42) ×520×12	Ksh 84,115
Estimated investment cost(Cost of 23.38 kVA) capacitor	30,000
Simple payback period (years)=$\frac{\text{Investment cost}}{\text{saving cost}} = \frac{30,000}{84,115}$	0.4
$\frac{S_1 - S_2}{S_1} \times 100 = \frac{68.9-55.42}{68.9} \times 100$	19.6%
$\% \ Reductiono \ \langle powerlosses = \left\{1 - (\frac{currentcosö}{newcosö})^2\right\} \times 100$	35.3%
As the result of PF correction from cos φ_1 = 0.724 to cos φ_2 = 0.90, active power transmission capacity is increased by 19.6 % and power losses are reduced by 35.3 %.	

[1]power factor surcharge for any installation whose PF is less than 0.9 lagging (appendix V)

2. **Filter room 1 motor (Rewinded)**

Table 8.3 Filter room-1 motor nameplate and measured parameters

	Nameplate parameters	Measured parameters
Current(A)	28	13.8
Voltage(V)	410	405
Rated power(KW)	15	-2.585
Rpm	1460	1460
Cos φ	0.84	0.268
FREQUENCY(HZ)	50	50

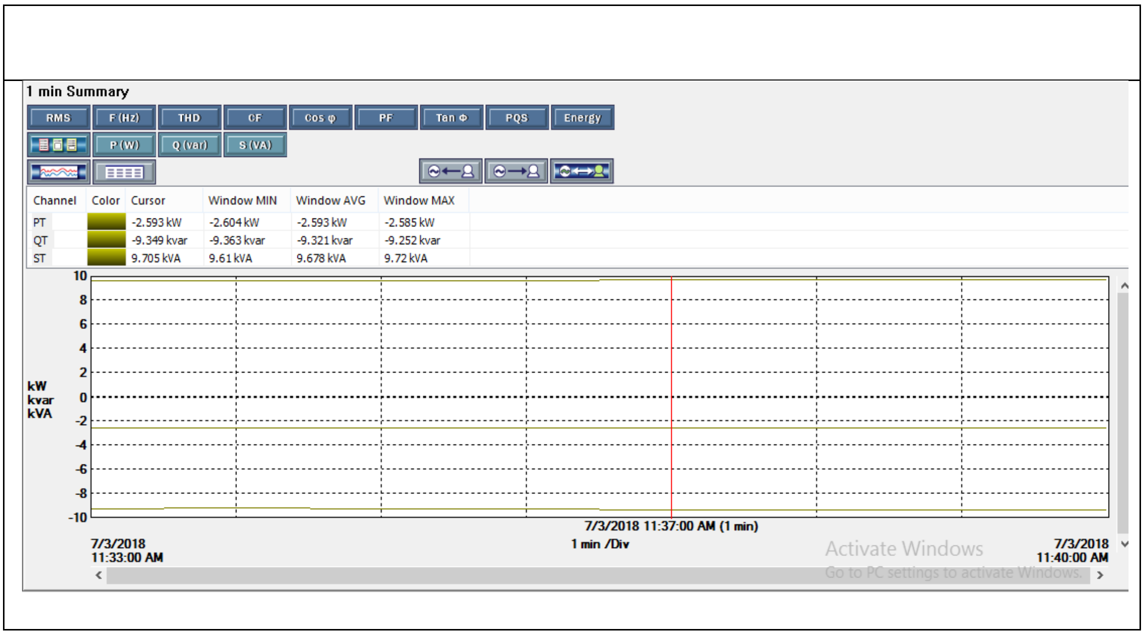


Figure 8.5: Power trends profile for Filter room-1 motor

Table 8.4 Power factor correction from 0.268 to 0.90 for Filter room-1motor

Existing situation	
Active power P	2.593kW
% of full load	17.3%
Exiting power factor (cos φ_1)	0.268
Resulting apparent power S1: $S_1 = \frac{P}{cos_{ö1}}$	9.675kVA
Improved situation	
Target power factor (cos φ_2)	0.90
Required capacitor rating Q_C: Q_C= P ×(tan φ_1-tan φ_2)	8.0966kVA
Apparent power S2: $S_2 = \frac{P}{cos_{ö2}}$	2.8811kVA
Potential savings pa= (S_1-S_2)×Demand charge Ksh 520×12 months	Ksh 42,394
Estimated investment cost(Cost of 8.0966 kVA) capacitor	20,000
Simple payback period (years)	0.5
$\frac{S_1 - S_2}{S_1} \times 100$	70.22%
$\% Reductionofpow撒rlosses = \left\{1 - (\frac{currentcosö}{newcosö})^2\right\} \times 100$	91.1%
As the result of PF correction from cos φ_1 = 0.268 to cos φ_2 = 0.90, active power transmission capacity is increased by 70.22 % and power losses are reduced by 91.1 %.	

3. Filter room-2 motor

Table 8.5 Filter room-2 motor nameplate and measured parameters

	Nameplate parameters	Measured parameters
Current(I)	27.3A	16.3
Voltage(V)	410 V	415.6
Rated power(Kw)	15	9.648
Rpm	1455	1455
Cos φ	0.87	0.832
FREQUENCY (HZ)	50	49

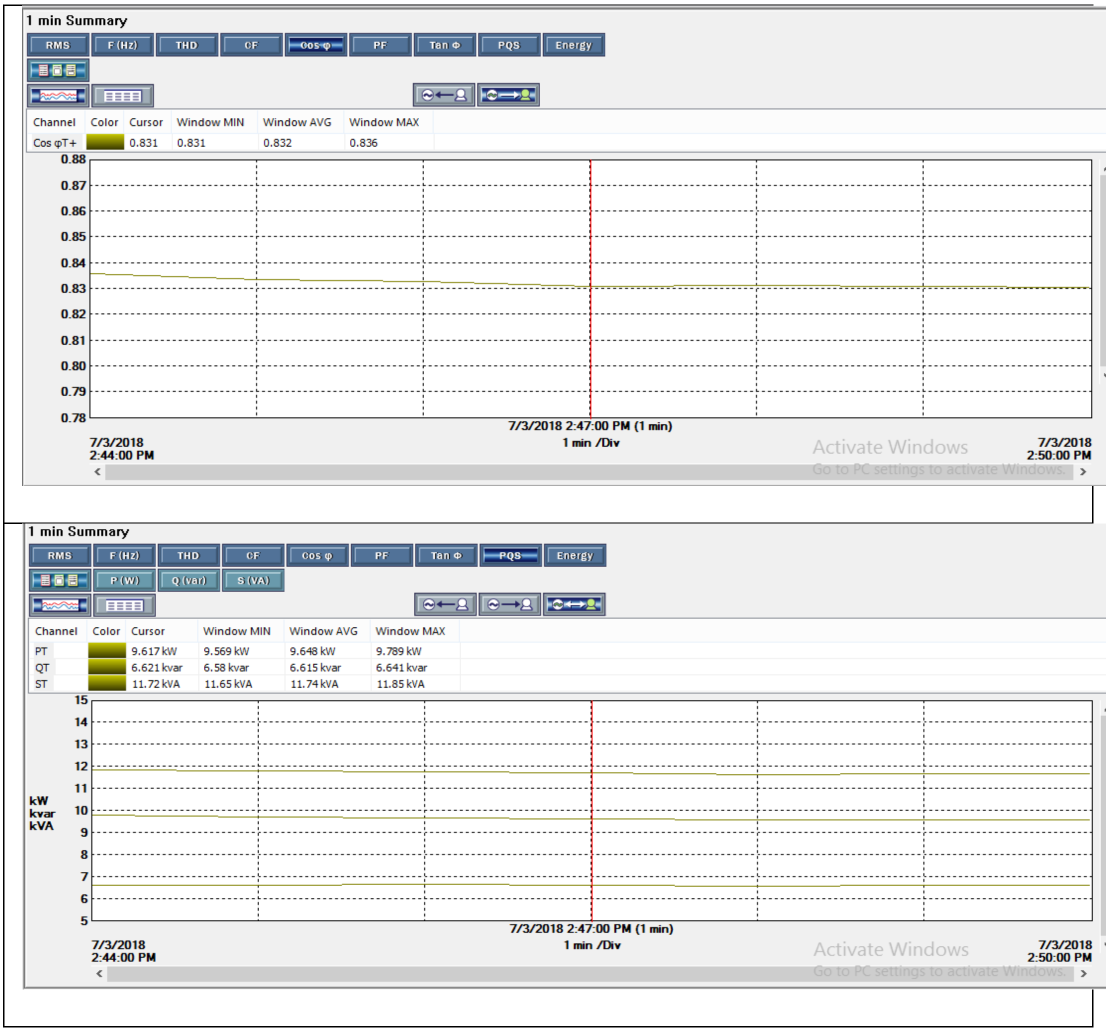


Figure 8.6: Power trends and power factor profile for Filter room-2 motor

Table 8.6 Power factor correction from0.832 to 0.90 for Filter room-2 motor

Existing situation	
Active power P	9.648kW
% of full load	64.3%
Exiting power factor (cos φ_1)	0.832
Resulting apparent power S1: $S_1 = \frac{P}{cos_{\ddot{o}1}}$	11.6kVA
Improved situation	
Target power factor (cos φ_2)	0.90
Required capacitor rating Q_C: Q_C= P ×(tan φ_1-tan φ_2)	1.77kVA
Apparent power S2: $S_2 = \frac{P}{cos_{\ddot{o}2}}$	10.72kVA
Potential savings pa= (S_1-S_2)×Demand charge Ksh 520×12 months	Ksh 5,491
Estimated investment cost(Cost of 1.77 kVA) capacitor	10,000
Simple payback period (years)	2
$\frac{S_1 - S_2}{S_1} \times 100$	7.5%
$\% \, Reductionofpowerlosses = \left\{1 - (\frac{curren\tau cos\ddot{o}}{newcos\ddot{o}})^2\right\} \times 100$	14.5%
As the result of PF correction from cos φ_1 = 0.832 to cos φ_2 = 0.90, active power transmission capacity is increased by 7.5% and power losses are reduced by 14.5%.	

4. Sizing motor (Rewinded)

Table 8.7 Sizing motor nameplate and measured parameters

	Nameplate parameters	Measured parameters
Current(I)	32.5A	8.6
Voltage(V)	415 V	395
Rated power(Kw)	9.5	1.624
Rpm	2500	2500
Cos φ	0.95	0.286
FREQUENCY (HZ)	50	49.95

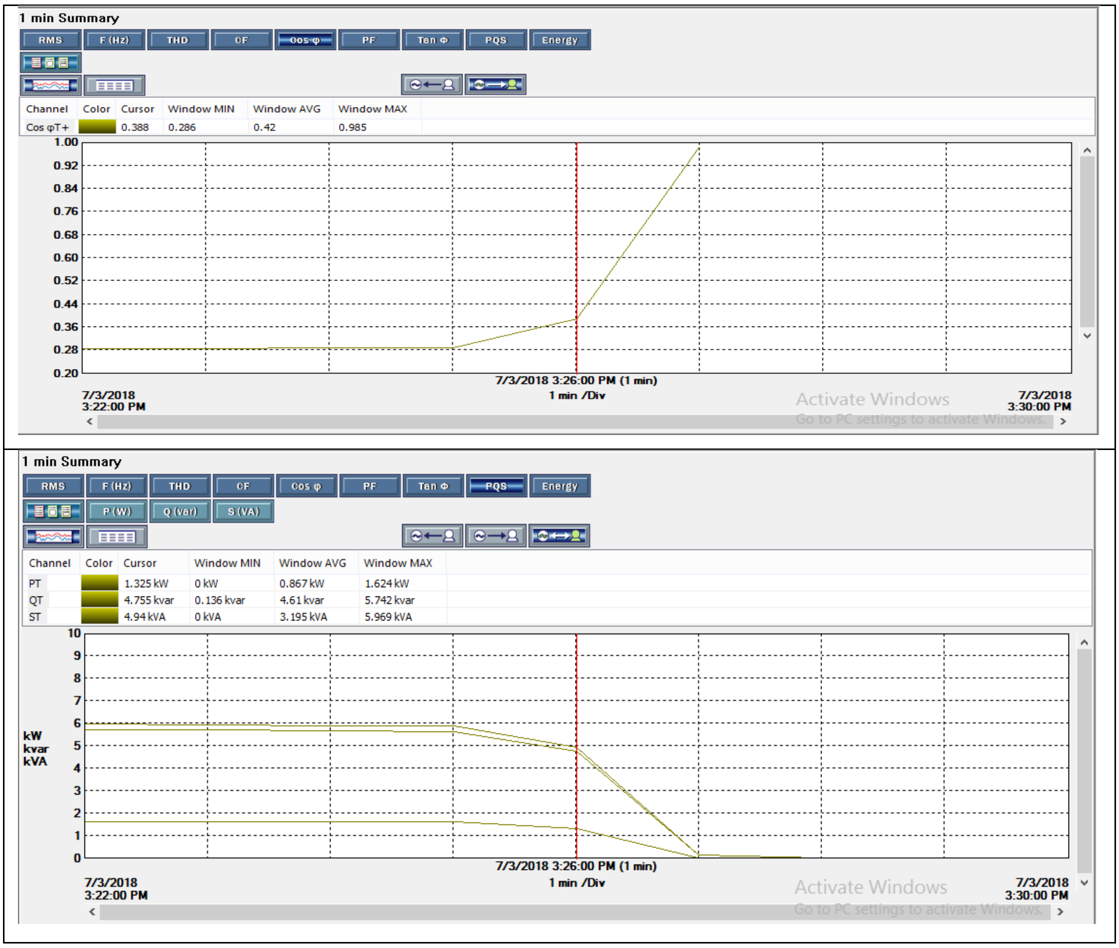


Figure 8.7: Power trends and power factor profile for Sizing motor

Table 8.8 Power factor correction from0.286 to 0.90 for Sizing motor

Existing situation	
Active power P	1.624kW
% of full load	17.1%
Exiting power factor (cos φ_1)	0.286
Resulting apparent power S1: $S_1 = \frac{P}{cos_{ö1}}$	5.678kVA
Improved situation	
Target power factor (cos φ_2)	0.90
Required capacitor rating Q_C: Q_C= P ×(tan φ_1-tan φ_2)	4.66kVA
Apparent power S2: $S_2 = \frac{P}{cos_{ö2}}$	1.8kVA
Potential savings pa= (S_1-S_2)×Demand charge Ksh 520×12 months	Ksh 24,170
Estimated investment cost(Cost of 4.66 kVA) capacitor	10,000
Simple payback period (years)	0.4
$\frac{S_1 - S_2}{S_1} \times 100$	68.3%
$\% \, Reductionofpowerlosses = \left\{1 - (\frac{currentcosö}{newcosö})^2\right\} \times 100$	89.9%
As the result of PF correction from cos φ_1 = 0.286 to cos φ_2 = 0.90, active power transmission capacity is increased by 68.3% and power losses are reduced by 89.9%.	

5. Step cleaner motor

Table 8.9 Step cleaner motor nameplate and measured parameters

	Nameplate parameters	Measured parameters
Current(I)	27.3A	18
Voltage(V)	410 V	415
Rated power(kW)	15	10.81
Rpm	1455	1455
Cos φ	0.87	0.84
FREQUENCY (HZ)	50	50

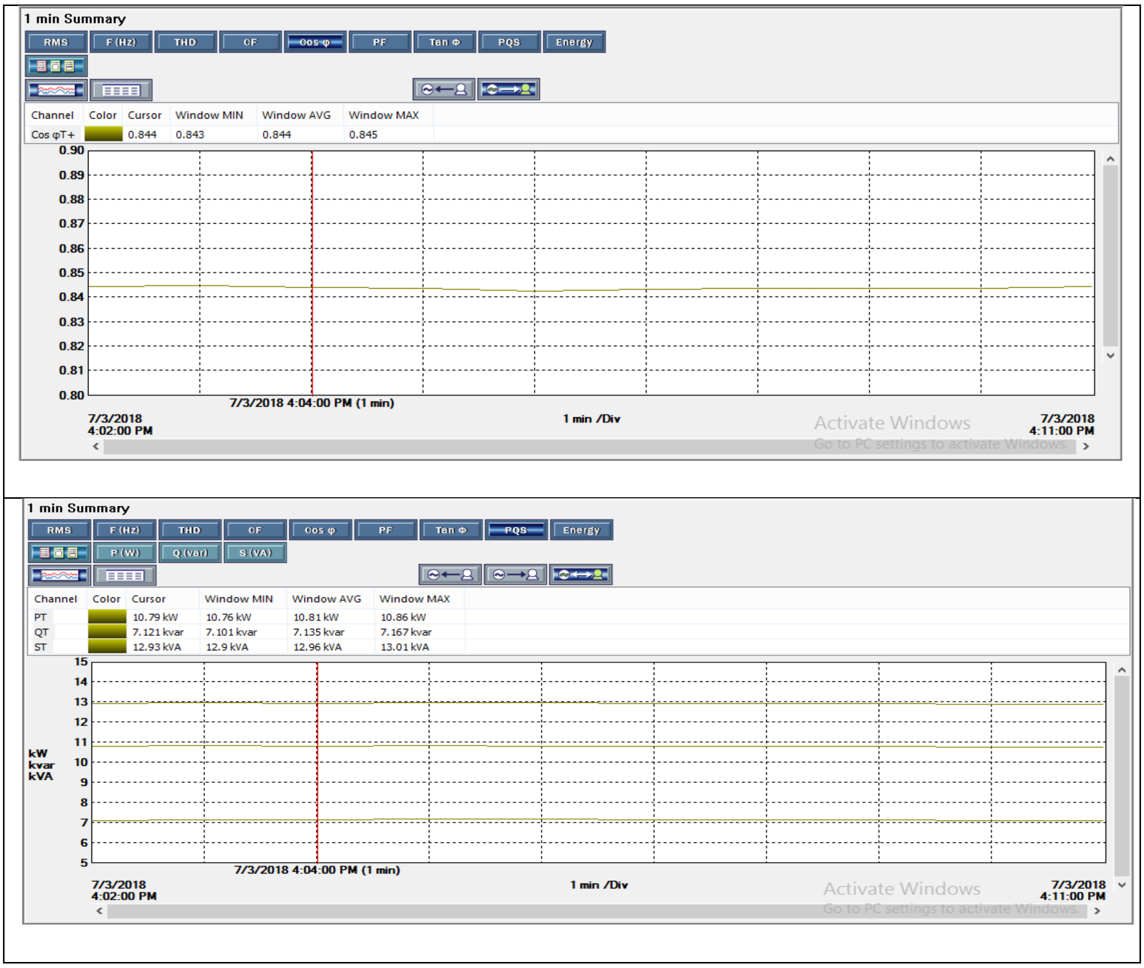


Figure 8.8: Power trends and power factor profile for Step cleaner motor

Table 8.10 Power factor correction from0.844 to 0.90 for step cleaner motor

Existing situation	
Active power P	10.81Kw
% of full load	72.1%
Exiting power factor (cos φ_1)	0.844
Resulting apparent power S1: $S_1 = \frac{P}{cos_{ö1}}$	12.8kVA
Improved situation	
Target power factor (cos φ_2)	0.90
Required capacitor rating Q_C: Q_C= P ×(tan φ_1-tan φ_2)	1.63kVA
Apparent power S2: $S_2 = \frac{P}{cos_{ö2}}$	12.01kVA
Potential savings pa= (S_1-S_2)×Demand charge Ksh 520×12 months	Ksh 4,923
Estimated investment cost(Cost of 1.63 kVA) capacitor	10,000
Simple payback period (years)	2
$\frac{S_1 - S_2}{S_1} \times 100$	6.17%
$\% Reductionofpowerlosses = \left\{1 - (\frac{currentcosö}{newcosö})^2\right\} \times 100$	12.06%
As the result of PF correction from cos φ_1 = 0.844 to cos φ_2 = 0.90, active power transmission capacity is increased by 6.17% and power losses are reduced by 12.06%.	

Appendix X: Ultimate Analysis of Fuel

Table 8.11 Ultimate analysis of wood

Content	%
Carbon	30.18
Hydrogen	3.72
Oxygen	25.85
Nitrogen	0.02
Sulphur	0.00
Ash	0.23
Moisture	40

Source: Isidoro , 1995-2018

Table 8.12 Ultimate analysis of Heavy oil

Content	%
Carbon	82.8
Hydrogen	8.9
Oxygen	2.0
Nitrogen	1.5
Sulphur	4.3
Moisture	0.5

Source: Loh et al., (2007).