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Energy Utilization and Saving Opportunities in Process Industries: Case Study of Textile Manufacturing Industry in Kenya

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Abstract: The industrial sector is seriously threatened by high energy costs brought on by inefficient energy use. Energy, together with labor and raw materials, make up the majority of production costs in the textile industry. As a result, the only real way for the textile industry to turn a profit and maintain its competitiveness is to reduce its energy costs through energy conservation measures and energy management strategies. The main objective of the study was to investigate energy utilization in textile manufacturing plant and identify energy saving and conservation measures that help reduce energy costs. In the current work, energy investigation was carried out to determine 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 were done. Energy utilization analysis showed that high electricity consumption occurs in spinning (48%), followed by weaving (26%) and wet processing (22%). Statistical analysis of energy consumption in spinning, weaving and wet processing showed linear relationship between production and energy consumption with correlation coefficients (R^2) of 0.782, 0.708 and 0.637 respectively which reveals that there continues to be a large potential of energy efficiency across all the major textile manufacturing processes in the plant. The study found potential savings in electric energy to be approximately 367,784 kWh/year, wood fuel savings 1,219 tones/year and furnace oil savings to be 22,275 L/year. The results displayed 31.6% overall energy cost saving potential with an average simple payback period of 0.5 years on the investigated high energy consuming utility systems and equipment. In conclusion, significant energy savings in the sector might be attained by implementing free or inexpensive investments including sealing air and steam leaks, insulating bare pipes, and properly drying wood fuel.

Keywords: Energy, Industry, Saving opportunities, Textile, Utilization

I. Introduction

The industrial sector has a significant issue as a result of poor energy utilization [1] and rising energy expenditures [2, 3]. Excessive energy consumption, particularly the use of fossil fuels, has contributed to environmental damage, climate change, [4] and the possibility of energy resource depletion[5]. Additionally, excessive energy use puts organizations' ability to compete at risk, particularly when energy costs are high [6].

Energy saving and conservation are vital for industrial sector which consumes large amount of energy to power diverse manufacturing processes [6, 7]. Increased energy costs in an industry have negative impacts on results and competitiveness, which in turn may lead to lower production and in some cases even cause enterprises to consider relocation [8]. On the other hand, effective energy utilization positively affects a company's overall costs directly and also in many cases leads to greater productivity which in turn leads to higher profits [9, 10].

Energy is one of the major inputs for the development of any country and a significant factor in economic activity on par with other factors of production like capital, land and labour [11]. Most firms, especially those in the manufacturing and processing industries, have one of their major controllable expenditures as energy, therefore there is significant room to cut costs by reducing energy consumption. The benefits are also reflected directly in an organization's profitability while also making a contribution to global environmental improvement in terms of energy conservation [12].

The efficient use of energy is of prime importance in all sector of the economy [13]. Efficient use of energy especially in developing Nations is critical in order to remain competitive globally and deliver profits to the shareholders [11, 14]. Also, for developing countries energy sector is of great importance due to huge investments demanding energy inputs to implement [15]. Energy used are from different forms which include mechanical, electrical, chemical, thermal and nuclear energy. Fossil fuels are expected to get depleted soon. In the last 200 years 60% of all energy resources have been consumed and today 85% of primary energy comes from non-renewable and fossil sources such as coal and oil [16].

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All over the world, energy is the key input and basic need in industrial facilities for development, economic growth, automation and modernization in the industrial sector [17]. Records show that industrial sector uses more energy than any other end user sectors and currently consumes about 37% of the total delivered energy globally [17]. Major Industries in the industrial sector which consume energy include; manufacturing, agriculture, mining, construction and wide range of activities such as processing and assembly, space conditioning and lighting [18, 19].

Manufacturing companies are being urged to cut their energy consumption globally in order to ensure a sustainable future. By promoting the employment of affordable, energy-saving alternatives to the current machinery and procedures, industrial energy management assessment is essential in helping facilities meet their energy efficiency targets[20].

World energy consumption is projected to increase by 33% from 2010-2030 [17, 21]. The most rapid growth in energy demand from 2006-2030 is projected for Nations outside the Organization for Economic Cooperation and Development (non-OECD). This is because, in recent decades, OECD countries have been in transition from manufacturing economies to service economies. Total non-OECD energy consumption was increased by 73% compared to a 15% increase in energy use among the OECD countries. Over the next 25 years, worldwide industrial energy consumption is projected to grow an average of 1.4% per year.

The manufacturing sector is the third largest energy end user in the Kenya economy. It is the second largest user of petroleum products after the transport sector and the largest consumer of electricity [22, 23]. The manufacturing sector in Kenya mainly uses electricity and oil as sources of energy in its production processes, distribution and transport services [5]. The utilization of these two forms of energy on average has been rising resulting in increased costs in terms of energy and total production [23].

Energy measurement helps to understand the consumption of energy and fuel in industry, identify energy wastage and potential energy saving opportunities. Energy measurement gives a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities.

In order to reduce energy consumption's for sustainable and energy-efficient manufacturing, continuous energy measurement and process tracking of industrial machines are essential. Energy measurement involves proper planning, directing and controlling of supply and input – output ratio of consumption of energy to maximize productivity and minimize energy costs [24-26]. The most energy-intensive manufacturing processes are assessed for areas for improvement with a focus on energy savings and associated advantages like cost savings and emissions reduction.

The primary objective of energy investigation is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy measurement provides a “bench-mark” for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization [27, 28]. Therefore, the aim of the study was to investigate energy utilization in textile manufacturing industry and identify energy saving and conservation measures that help reduce rising energy cost.

II. Methodology

Energy investigation procedure

Energy investigation in the case study industry was done to establish types and costs of energy inputs, breakdown of energy consumed, specific energy consumption per department, present pattern of energy consumption in different cost centers of operation and relationship between energy input and production output. The following procedure was used in energy investigation;

1. Historical energy consumption and production data for past two years for spinning process, weaving and wet processing was collected to evaluate the characteristics of the energy systems and the patterns of energy use for the plant.
2. Utility bills for the past two years were used to determine the unit cost of various energy inputs. Also, periods of operation and annual plant and equipment operating hours was noted.
3. Specific energy consumption (SEC) for yarn, woven fabric and finished fabric was determined using the following formula [29, 30];

$$SEC = \frac{Energy\ Consumption(E)}{Production(P)} \quad (1)$$

4. 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 [11].

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Research instruments

a) Flue gas analyzer

Flue gas analyzer - Testo 310 was used to measure O_2, CO_2 and CO in ppm and flue gas temperature of boilers.

Figure 1: Flue gas analyzer-Testo 310

b) Power and energy logger

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.

Figure 2: Power and energy logger - PEL 103

c) Lux meter

Lux meter was used to measure illumination level

Figure 3: Lux meter

d) Clamp meter

Clamp meter was used to measure current

Figure 4: Clamp meter

e) Infrared thermometer

Infrared thermometer was used to measure surface temperature of boilers and steam pipes.

Figure 5: Infrared thermometer

III. Results and Discussion

Breakdown of energy use in the plant

The main sources of energy utilized in the case study textile manufacturing plant are electricity, wood fuel and furnace oil. Electricity is mainly used to run motors and lighting while furnace oil and wood fuel are used in boilers basically for treatment of yarn and woven fabric.

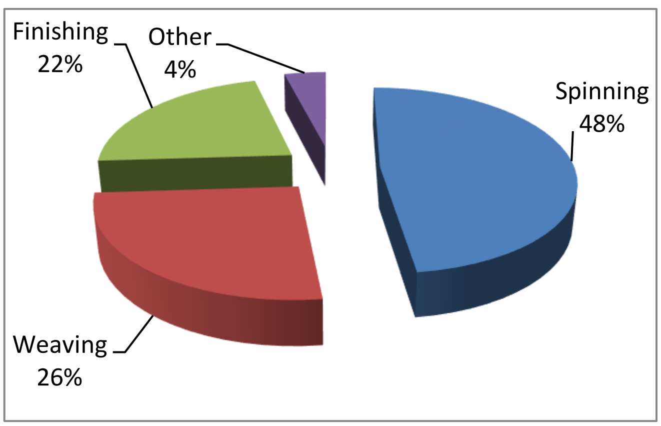

Figure 6: Breakdown of Electricity use in textile industry

The analyzed data presented in figure 6 shows that highest electricity energy consumption in textile industry occurs is spinning process (48%) where the machines are completely driven by electric energy. Weaving process (26%) is another high electricity energy consuming processing stage. It uses also steam for sizing yarns to improve its properties before warping. Wet processing (22%)is heat and steam intensive processes where electric energy is only consumed for mechanical driving purposes. Wet processing utilizes steam and heat for dying, curing and drying of the woven fabric.

Specific energy consumption

Energy intensity is the amount of energy consumed to produce a unit amount of product and it is a measure of the energy efficiency of the industry.

In the case study textile manufacturing plant in Kenya, the intensity of electricity for spinning process was found to be 2.5kWh/kg. It is 36% higher than the best bench marked country (Brazil) shown in table 1. The intensity of electricity for weaving process and

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finishing (wet) was found to be 1.2kWh/kg and 1.0kWh/kg respectively.Results show that the studied industry has an opportunity to reduce production costs and enhance energy performance by using energy-saving and conservation measures.

Table 1**:** Comparison of specific energy consumption for Kenya and other countries

Countries	Electrical energy	Open end	Yarn
	prices, \$/kWh	Energy consumption, kWh/kg	Energy cost, \$/kg
China	0.080	1.625	0.13
India	0.095	1.684	0.16
Turkey	0.140	1.667	0.14
Brazil	0.050	1.600	0.08
S. Korea	0.100	1.667	0.10
USA	0.045	1.778	0.08
Italy	0.084	1.714	0.18
Kenya	0.20	2.500	0.50

Statistical analysis of energy use and production for the plant.

Statistical analysis shows how a dependent variable (energy) is related to the independent variable [31] by providing an equation that allows for estimating energy consumption for the given production output while 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 that linear relationship between production and energy consumption exists in spinning, weaving and finishing (wet) processes with correlation coefficients (R^2) of 0.782, 0.708 and 0.637 respectively which reveals that there continues to be a large potential of energy efficiency across all the major textile manufacturing processes in the plant.

Performance analysis of energy systems and energy saving and conservation measures

a) Boiler system

Steam is the heart for textile processing. Boiler is mainly used for drying, dyeing and heating. 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 is important to determine deviation of boiler efficiency from the expected performance for corrective action.

Table 2: Flue gas test results for Wood fired tube boiler

Flue gas analysis data- Testo 310				
	Sample 1	Sample 2	Sample 3	Average
Flue gas temperature, T_f	395.1ºC	329.7ºC	389.3ºC	371.4ºC
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	23.0ºC	24.6ºC	24.0ºC	23.9ºC

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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(^{o}C)				23.9^{o}C
Wet bulb temperature (^{o}C)				17^{o}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

Source: Researcher's experiment, 2018

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

Boiler efficiency was calculated using heat loss method.The instantaneous energy balance for the wood fire tube boiler was done by taking samples 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 in table 2.

Based on the results of the measurements shown in table 2 and optimal flue gas composition in table 3, the following observations were made;

1) Oxygen composition in flue gas was found to be 10.6% higher than the optimal flue gas composition.
2) Carbon dioxide composition was found to be 16% lower than the optimal flue gas composition.
3) Flue gas temperature was found to be 171.4^{o}C higher than the optimal flue gas composition.
4) The overall boiler efficiency was found to be 17.35% against designed efficiency of 75%. 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%.

From the results, the following energy saving measures for boiler system were identified;

1) Excess air control- If the percentage of excess air is adjusted to optimum levels as per table 3 to obtain the required CO_2 percentage (15.5%) and oxygen (5%), the boiler efficiency would increase by 39.63% to 56.98%.
2) Reducing moisture content of wood fuel- The efficiency of boiler is greatly affected by the quality of fuel. Proper drying and preservation of wood fuel is necessary to improve quality [32, 33]. 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.

Table 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: [34]

For this research reducing moisture content of fuel from 40% to 20% was found to improve boiler efficiency by 7.39%.

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3) 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 7: shows fresh wood fuel used

4) Boiler maintenance should be done regularly and removing the scale and ash deposits [35] on the fire tubes should be given priority as these deposits act as insulation thus preventing heat transfer between flue gas and boiler water.

Figure 7: shows some blocked fire tubes of wood- fire tube boiler due to ash deposits

High percentage of heat losses is due to the high temperature of dry flue gases leaving the boiler.

5) Waste heat recovery should be employed to utilize high temperature of flue gases which is currently vented to the atmosphere [36]. Flue gas temperatures above 200^{o}C can be used to increase boiler feed water temperature or dry wood fuel to achieve moisture content below 25^{o}C. Significant energy savings can be achieved from the reuse of the high temperature condensate.

b) Lighting system

Due to the nature of operation in the case study industry, the share of electricity use in lighting is relatively high. Though lighting system energy consumption is minimal compared to other systems such as motor system and air compressor system in the industry, room for energy saving opportunities exists. Incorporation of modern energy efficient lamps is an opportunity to achieve energy efficiency in lighting [14]. The main objective of efficient lighting is to provide the required lighting effect at the lowest power consumption.

Lighting measurements for the factory under study taken with lux meter showed poor illumination levels compared to the recommended standards.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;

1) Adjusting the number of luminaires to recommended levels
2) Replace T-12 Fluorescent with T-8 LED lamps
3) Installation of skylights is necessary to avoid usage of artificial lighting during the day. Also, utilizing natural lighting in the factories could reduce the amount of electricity required.

c) Air Compressor

The industry utilizes rotary screw air compressor to operate pneumatic machines. The power consumption of air compressor was measured with power and energy logger. Air leak test during shut down was performed to determine the extent of percentage air losses by air compressor. The major opportunity to save energy is in the prevention of leaks in the air compressor system. Leaks

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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.

The study found air leakage to be 50.2% and energy loss due to leakage per day to be 523.88 KW. The results present huge potential of energy saving through leakage repair. Other energy saving opportunities identified for compressed air systems includes;

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

d) Motor system

Textile industry under study uses a vast number of relatively small motors to run machines. Motors are the main energy consumers in the industry. Rewinding of motors is common and a sample of motors was selected to determine the power factor against nameplate parameters. The power and energy logger instrument were used for performance measurement. From the results of sampled motors, it was noted that power factor for rewinded motors was very low as well as percent loading. Sizing motor displayed a power factor of 0.286 and 17.1% of full load while filter room-1 motor displayed a power factor of 0.268 with 17.3% of full load. It is important for the industry to invest on portable power and energy logger instruments to be used to test efficiencies of rewinded motors before use.

Table 4: Summary of energy saving opportunities for the case study industry

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	1,000,000	0.3
2	Motor retrofit	10,163 kWh/year	161,093	80,000	0.5
3	Steam systems insulation	22,275L/year	1,275,386.40	330,000	0.3
4	Lighting systems retrofit	200,457kWh/year	4,009,140	1,927,800	0.5
5	Boiler systems-wood boiler	1,219 ton/year	2,682,900	1,895,000	0.7
	TOTAL		**11,271,799.4**	**5,232,800**	0.5
	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**			
	% potential savings	**31.6%**			
	Average payback period	**0.5 years**			

The significance of installing capacitors to reduce losses was also noted. High PF further more results in decreased transmission losses and improved motor efficiency. The industry has a significant chance to reduce energy costs by investing in capacitors to increase PF[37].

a) Steam distribution system

The set up of the industry requires extensive use of steam distribution pipes to transport steam to different point of use.

It was observed that substantial steam losses occur due to leakages caused by corroded steam pipes. Also noted was missing lagging in various parts of the steam pipes due to poor maintenance. Uninsulated steam distribution and condensate return systems are major sources of wasted energy. Lagging of steam pipes reduces energy losses by 90% and ensures delivery of steam to plant equipment at recommended pressure [38, 39] .

The advantage of proper insulation is the use of less steam and fuel consumption in raising temperature which reduces the cost of production. The risk of steam pipe burns is reduced by a well-lagged system, which also minimizes excessive heat in the workplace. In order to prevent energy losses through radiation, it is advised that all exposed surfaces of steam and heat pipes be properly insulated.

IV. Conclusion

This paper's goal was to examine energy use and identify energy-saving and energy-conservation practices in textile manufacturing facilities in order to lower rising energy costs. Implementing best technical practices and energy conservation measures would significantly lower the industry's vast energy saving prospects and the rising cost of energy. A detailed performance analysis of numerous utility systems revealed that the primary energy-intensive systems are the motor, air compressor, lighting, steam distribution, and boiler systems. The study found potential savings in electric energy to be approximately 367,784 kWh/year, wood fuel savings 1,219 tones/year and furnace oil savings to be 22,275 L/year. The results displayed 31.6% overall energy cost saving potential with an average simple payback period of 0.5 years.

The study demonstrated that the textile manufacturing industry may save a considerable amount of energy by making low- to no-cost expenditures such as caulking air and steam leaks, employing energy-efficient lighting, insulate bare pipes, and correctly drying wood fuel.Although the research concentrated on energy-saving and conservation strategies in the textile manufacturing sector, the prospects found apply to other sectors with a similar business model.

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