Energy Performance Analysis of Beverage Industry- a Case of Coca Cola Beverages Africa

Meseret Yeshaw Demissie

A Thesis Submitted to

The Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

June, 2024

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DECLARATION

First, I hereby declare that this Master of Science Thesis entitled *"Energy Performance analysis of Beverage Industry- a Case of Coca Cola Beverages Africa"* is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Meseret Yeshaw		
Name of student	Signature	Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled *"Energy Performance analysis of Beverage Industry- a Case of Coca Cola Beverages Africa"* prepared under my guidance by Meseret Yeshaw Demissie submitted in partial fulfillment of the requirements for the degree of Master of Science in Thermal Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Addisu Bekele	____________	____________
Name of Advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled hereby *"Energy Performance analysis of Beverage Industry- a Case of Coca Cola Beverages Africa"* and developed by Meseret Yeshaw Demissie, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Addisu Bekele	______________	______________________
Name of Advisor	Signature	Date

We, the undersigned members of the Board of Examiners of the thesis by Meseret Yeshaw Demissie have read and evaluated the thesis entitled *"Energy Performance analysis of Beverage Industry- a Case of Coca Cola Beverages Africa"* and examined the candidate during open defense. Therefore, this is to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Thermal Engineering.

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LIST OF SYMBOLS AND NOMENCLATURES

AAS	Actual Mass of Air Supplied per Kg of Fuel
AEC	Annual Energy Consumption [Kwh]
AES	Annual Energy Savings [Kwh]
BPH	Bottle per Hour
CC	Crown Cork
CCBA	Coca Cola Beverage Africa
C_p	Specific Heat [kJ/kg]
CIP	Clean in Place
CSD	Carbonated Soft Drink
EBI	Empty Bottle Inspection
FBI	Full Bottle Inspection
FBS	Full Bottle Store
I_m	Measured Current [A]
M	Mass of Moisture in Fuel in 1kg Basis [%]
p.f	Power Factor [%]
PEBI	Pre-Empty Bottle Inspection
PET	Poly Ethyl Terephthalate
P_{in}	Power Input [Kwh]
Q_{in}	Heat Input [Kw]
RA	Theoretical Air Required [Kg of Air/kg of Fuel]
RGB	Returnable Glass Bottle
T_a	Ambient Temperature [^{O}C]
T_f	Flue Gas Temperature [^{O}C]
V_m	Measured Voltage [V]
V_r	Rated Voltage [V]
η	Efficiency [%]

ABSTRACT

Serious concerns over energy prices and demand have been highlighted by the rising usage of energy. This study's goal is to investigate energy performance analysis in the east Africa bottling Share Company. Examining the energy-consuming equipment's performance is the first step in performing a thorough energy analysis. The factory's utilization of energy and potential in savings of energy are analyzed in this thesis. The study's foundation is the knowledge that there is highest room for improvement in terms of energy efficiency in the industrial machinery that is currently in use.

The evaluation of the steam boiler's performance and bottle washer performance are based on the actual measured data and takes various heat losses into account. Boiler and bottle washer for line one, three and five efficiencies was typically 84.81%, 74.43%, 71.96% and 68.166% respectively. A portion of the energy that remains becomes wasted as heat in various forms. The investigation indicates that dry exhaust flue gas is the primary cause of heat loss. This analysis also determines the yearly savings prospects and driving electrical motor use.

The analysis revealed that the company had significant potential for energy savings. Using different methods for energy savings, it has been shown that the industry may save 3,716.33 GJ annually in heat energy recovered from dry exhaust flue gas to preheat combustion air, as well as 140,536.91kWh annually by converting to highly efficient motors from traditional motors. This means that the company might save a total of 8,512,785.335 ETB in bills annually.

Keywords: *Steam boiler, Bottle washer, Electrical motor, Efficiency, Savings*

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Both thermal and electrical energy is used by beverage industries for a variety of tasks, including heating, sterilizing, bottling, and refrigeration, among others. Industry Week reports that greater rivalry, narrower margins, and growing energy prices are the main forces behind food and beverage producers' need to manage energy use. For the majority of food and beverage facilities, electricity is the biggest energy expense, but it also has the most savings potential and has the quickest payback period.

Energy savings are abundant in manufacturing processes and transformation phases involving heating, tempering, annealing, drying, curing, and other operations. Finding energy-efficient solutions requires an understanding of these processes, as well as the tools, technology, and support systems that go along with them.

1.2 Statement of the Problem

Electrical and thermal energy are utilized in motor, boilers, pumps, refrigerators, compressor and other machinery in all beverage industries and factories. Nevertheless, the industry sectors face several challenges in effectively utilizing their energy resources. As a result, the manufacturers are vulnerable to excessive energy costs, environmental issues, unprofitability, and decreased competitiveness. As a result, the CCBA Company utilized both thermal and electrical energy for the production of soft drinks. The thermal energy is generated by burning of diesel fuel to produce saturated steam of 8 ton/hr and 8 bar pressures. This steam is used in bottle washer, sugar dissolving, CIP (clean in place), pasteurization, sugar treatment and carbon filter. In the CCBA there are four production line, but not all the day the four line is active it may be under CIP (clean in place), maintenance or breakdown. During this period the boiler still produce the same amount and quality of steam, so the unnecessary steam is simply drawn to the environment. The steam trap is not properly functioning which leads to have steam leakage and there is no sufficient insulation in the steam pipe transition line.

1.3 Objective of the Research

1.3.1 General Objective of the Research

The general objective of this thesis is to investigate and analyze the way energy is being utilized in beverage industry a case of Coca Cola Beverages Africa and identify energy saving potential to reduce energy costs after implementation.

1.3.2 Specific Objective of the Research

The specific objectives of the research are: -

- Review energy consumption profile of Coca Cola Beverages Africa
- Identifying highly energy consuming process and equipment
- Determining energy losses
- Identifying possible energy conservation opportunity

1.4 Significance of the study

Nowadays, our country is linked to both alcoholic and non-alcoholic beverage companies. These companies utilize a significant amount of electrical and thermal energy. By consuming coal or furnace oil to generate thermal energy. The key to establishing how much thermal energy is utilized, how much thermal energy is worth utilizing for beverage production, where waste energy is located, and how to implement an energy conservation action plan is to do analysis of thermal system energy consumption results. This research enables CCBA understand its fuel consumption pattern and implement energy-saving measures, which will save fuel costs and prevent pollution of the environment.

1.5 History of the company

The carbonated soft drink often referred to as Coca-Cola, or Coke, is made by the Coca-Cola Company. John Stith Pemberton invented it in Atlanta, Georgia, in the late 1800s, and it was initially marketed as a temperance beverage with the goal of becoming a patented medicine. In 1888, Pemberton gave Asa Griggs Candler ownership rights of the business. Coca-Cola became the dominating force in the soft drink business in the 20th and 21st century because to Candler's marketing methods. The drink's name refers to two of its original ingredients, coca leaves and kola nuts, both of which contained caffeine.

The Coca-Cola Company manufactures concentrate and supplies licensed Coca-Cola bottlers worldwide. The concentrate is used by the bottlers, who have exclusive territorial agreements with the firm, together with sweeteners and filtered water to make the finished product that is packed in bottles and cans.

With roughly 70,000 workers spread across 160 factories, it has been operating in almost every country on the continent since 1929 and is among the biggest employers in Africa. It is enormous, with over 35 billion Coke bottles purchased annually by Africans.

The largest bottler of Coca-Cola products in Ethiopia is East Africa Bottling Share Company (EABSC), a part of CCBA, with 60 years of expertise. In 1959, the nation's capital, Addis Ababa, saw the launch of Coca-Cola bottles by the East Africa Bottling Share Company. The firm opened a second branch in Dire Dawa two years later, in 1965. The two facilities were nationalized in 1975 and continued to function as publicly listed companies until 1996, when private investors purchased them. Prior to that, in 1995, the firm's stock was acquired by the Coco-Cola South African Beverage firm (Coca-Cola SABCO), and in 1999, a joint venture agreement was established between the plants and the company. Coca-Cola SABCO increased its holding position to 61 percent and renamed the company the East African Bottling Share Company. EABSC continues to run the two plants in Addis Ababa and Dire Dawa. In Addis Ababa, 36,000 PET bottles may now be made in an hour. The third branch is where Bahir Dar . The two lines were able to produce up to 72,000 RGB bottles each hour when they were built in 2016. Since the business opened, more than 400 people have had the opportunity to find job.

EABSC's Greenfield facility at Sebeta, the country's largest Coca-Cola factory, opened its doors in May 2022 and has the ability to manufacture 352,000 cases daily, with an average production of 72,000 cases per day. This production will be distributed throughout the South-East and portions of the Southern regions of Ethiopia. At the moment, the corporation runs four plants: Dire Dawa, Bahir Dar, Sebeta, and Addis Ababa. Ambo Mineral Water Share Company (AMWSC), another CCBA associated, has a successful 90-year history in Ethiopia.

CHAPTER 2

LITERATURE REVIEW

2.1 Studies carried out in Ethiopia

Lami (2019) conducted an energy audit at the Ambo Mineral Water Factory, emphasizing the equipment, including the steam distribution system, air compressor, water pump, electric motor, and boiler. 21 months' worth of data were gathered and examined for the auditing process utilizing portable instruments. Following a thorough energy audit, the following course of action is suggested: replacing the current electric motors and water pump might save approximately 46,000 ETB and 128,000 ETB annually, respectively; repairing the feed water treatment plant and insulating the boiler surface would save approximately 267,800 ETB and 26,300 ETB annually; and replacing the steam distribution line could save approximately 71,700 ETB annually.

Samuel (2009) executed an energy evaluation in Mekanissa alcohol industry. Equipment such as distillery columns and pump, boiler, air compressor, and prime mover was selected from the nine-energy system of the factory. To determine the boiler's first law efficiency and the associated Sankey diagram, an energy balance was performed. The boiler is oversized according to the energy audit. The proposed solution for this was to replace the boiler with one that was appropriately sized to save annual fuel costs of 560, 363.44 ETB.

Yibeltal (2011) conducted an energy audit in Sebeta Alcohol and liquor factory. The plant's reported issues included incorrect water treatment, inappropriate boiler maintenance, a lack of an automatic blowdown control system that causes excessive blowdown, and an imbalance between the factory's demand and supply of steam. After the energy audit was finished, the following suggestions were made: replacing the motor; by installing double-pipe heat exchanger to get heat from the effluent and reduce energy consumption by 43.076 kW annually; fixing boiler feed water treatment to reduce energy consumption by 29.05 kW annually; and insulating the boiler surface in order to avoid radiation and convection losses as well as the distiller surface and steam distribution pipeline.

2.2 International studies

Mousa and Bilal (1998) carried out The energy evaluation of the steel production sector, and it determined significant thermal losses in the primary components of the industry, which ranged from 19 to 36% of its total amount of energy input. The boiler lost 36% of the overall heat input, the furnace's crucible and mold lost 17% of the total heat input, and the chiller rejected more than 26% of the total heat input.

Saidur and mekhiref (2010) studied on rubber processing industries in Malaysia analyze their energy usage, energy savings, and emissions. To determine the areas that should get the auditors' primary attention during the audit process, a meeting with pertinent plant staff was convened. Electrical motors, process heat, air conditioning system, air compressor, pumps, workshop equipment, and lights are all subjected to an energy audit. This means that using variable speed drives and high efficiency motors for industrial motors may save a staggering amount of energy and electricity bills. When energy-saving techniques are used to industrial motors, emissions may be significantly decreased, and at higher speeds, even more energy can be saved. The payback period for implementing these tactics is fair for certain variable speed motors.

Ajani (2016) conducted an energy audit at the Nigerian Niger state-based Hommec Technology Company in Serja. Measurement, key person interviews, and observation were the main methods used to collect data. The following method was used to do a thorough examination of the data: power flow diagram, analysis of the data gathered, and determination of the cause of the discrepancy between connected load and real consumption, the factory's total load was determined to be 82.145 kW. The study found that energy-saving compact fluorescent lamps can significantly reduce energy consumption when used in place of convectional tube lights. It also showed that proper maintenance and control are necessary to increase energy efficiency and that the industry's planned 14-month payback period for energy audits.

Abdi (2021) carried out an investigation of the pasta and macaroni industry's energy efficiency. According to the Africa P.L.C. instance, dryers-2, -3, and -4 use 6,885 TJ/year, 9,539.6 TJ/year, and 10,132.5 TJ/year of energy yearly, respectively. Following a thorough examination, dryer-2, dryer-3, and dryer-4 should have thermal efficiencies of 75.3%, 80%, and 73.1%, respectively, for conventional dryers. In all, Plants-2,-3, and-4 used 26%, 36%, and 38% of the 7,376,971 kWh of thermal energy that was produced annually. According to the report, there is a large opportunity for energy savings in the business. After implementing a number of energy-saving strategies, it was discovered that the sector could save 262,681.4 kWh annually by switching to high-efficiency motors from conventional motors, 782,6 GJ annually from thermal energy recovered from dry combustion air to preheat the combustion air, and 1,221 GJ annually over a five-year period. Utilizing an oxygen analyzer can help you manage extra combustion air. This suggests that there would be a possible yearly bill savings of about ETB 1,676,872 for the facility.

Sattari et.al,(2007) investigated the energy use of 17 sugar cane plantations in Iran, the author discovers opportunities for energy conservation. Depending on the stages of the manufacturing process—sugar beet, cane sugar, beet and raw sugar, and raw sugar refining—the energy intensity of sugar production ranges from 34.6 to 49.8, 24.7, and 10 GJ/ton. As a result, 27 GJ/ton was the average energy intensity across all industries. Utilizing fan speed controls, electrical motor use guidelines, and highly efficient motors are additional viable energy-saving tactics.

Ziya et al., (2010) constructed a mathematical model to evaluate a rotary kiln heat recovery unit's performance. It was discovered that 73% of the lost heat could be recovered and transferred to the working fluid by using the heat exchanger form that was recommended. These findings show that the cement industry uses between 4 and 5 GJ per ton of specific thermal energy.

Karamarkovic et al., (2013) studied heat losses from the rotary kiln and exhaust gases were determined to be 26.35% and 18.95% of the input energy, respectively, in a magnesium manufacturing facility. They advise using a circumferential duct heat exchanger to prevent heat loss. By reducing fuel consumption by 12%, the annular heat exchanger may increase energy consumption and system efficiency by 7.53%.

Wang et al., (2013) carried out the rotary kiln in a cement manufacturing plant uses 85% of the energy required to produce clinker. Heat loss from radiation and convection on the outside of the rotating kiln might reach fifteen percent. Using a prototype rotary kiln, researchers ran experiments to see how the heat recovery unit's operation was impacted by operating conditions. It has been shown that raising the working fluid's temperature tends to reduce heat losses through the environment.

Rejane et al., (2018) Data was acquired and an analysis of the energy consumption in each sector was carried out during the whole industrialization process of milk. By looking over the agreements with the energy provider, the power bills were examined. Inspections have been performed on the air conditioning, heating, ventilation, and lighting systems. The energy consumption of 63active and reactive power has been validated, taking into account the time of day and season as well as the contracted and used active power, the installed load and the most important processing machinery. It was also determined how much fuel was utilized in the boilers that produced the thermal energy needed for the pasteurization process. The company's potential for energy savings for its end users was recognized, along with possibilities to deploy energy-saving solutions, after the survey findings were analyzed. It is recommended that fluorescent bulbs be installed to the lab benches' lighting system in order to meet the minimum illuminance value required for this type of work as stated by the applicable technical standard. Reducing the power of the lamps in the administration sectors is recommended in order to save cost on lighting, since it is feasible to make effective use of natural sunshine there and the lights' verified value is far more than the minimum suggested by the relevant technical standard. Since the bulbs used for outdoor lighting account for 34% of the energy needed for illumination, it is advisable to set up light and motion sensors to reduce the amount of time the lamps are left on at night. The primary suggestion for cutting costs in the air conditioning industry is to switch out window air conditioners with more cost-effective split units. It is suggested that when purchasing new appliances, the power should be checked in accordance with the available facilities and activities. As a result, equipment with power much beyond what is required for thermal comfort in the administrative spaces was confirmed to have created unnecessary air conditioning expensesDespite the lack of direct electrical quantity measurements on the motors, an analysis of the load factor and power factor gleaned from the electric power bills allows one to conclude that certain operational modifications to the motors would result in a significant reduction in energy consumption. Thus, the main recommendation for improving the energy efficiency of the sector is to do these tests and modifications.

Talwar and Kumar (2015) the aim of the study was to present the Hindustan Coca-Cola bottling factory's production process characteristics. It came to the conclusion that the firm uses a lot of energy and releases a lot of pollutants. The Jammu plantations of Hindustan Coca-Cola have significant challenges in their sustainable growth due to energy limited resources and environmental factors. Hindustan Coca-Cola's annual energy expenses were around 36 million at the time. It is anticipated that energy prices will drop by more than 10% with the installation of EMOs.

Harit et al. (2013) used auditing techniques to do analysis on cost and energy for the paper and pulp industry. It was discovered that the older models of pumps required greater electrical power. It has been shown that deploying pumps with the same capacity but higher efficiency can save 50% of energy when compared to older models. It is discovered that self-suction of the black liquor from the washing bucket is feasible by raising the barometric foot height from 10 to 13 meters. This eliminates the need for two vacuum pumps, saving 100% of the cost and energy. Scaling issues in boilers shorten their service life and increase localized corrosion. Therefore, TDS blow down valves were used in boilers to replace manual blow down valves, saving 5% to 8% upon fuel. Interlocking devices were installed in the stock preparation process since it was seen that some of the agitators were running constantly, wasting electricity. It was discovered during the audit that the paper machine's steam cylinder dryer heads were not insulated, which increased heat loss from the heads. As a result, it was advised to insulate the heads to lower energy consumption; the expense of doing so may be recovered in five to six months.

Bar and Voigt (2019) Provided analysis and forecasting techniques for the beverage industry's media demand and energy efficiency. The brewery's primary users and consumption patterns are listed to identify possibility of energy savings. It provides a brief explanation of current methodologies, including benchmarking, simulations, pinch assessments, and real-time operating systems, along with a description and classification of relevant articles pertaining to the beverage sector. Simulation may be used to provide a thorough analysis and forecast of energy and media consumption in the brewery, as shown by the critical comparison of the different approaches. A comprehensive modeling and simulation technique was suggested because the data base is largely inadequate, and this method necessitates specialized knowledge.

Olyinka et al., (2015) provided a study of energy use and potential savings in a chosen sector in southwest Nigeria. An electric motor accounts for between 40 and 70 percent of total energy consumption, according to the findings of the energy audit carried out at the selected processing and production enterprises. The information that was easily accessible showed that, at 5,039.45 TJ/year, the food processing business consumed the most energy, while the ceramics industry used the least, at 109.43 TJ/year. Between 28 and 108 MJ/kg were consumed by the food processing business, 3.72 to 3.96 MJ/kg by the distillation and bottling industry, 76.55 to 92.80 MJ/kg by the chemical industry, and 7.71 to 7.93 MJ/kg by the ceramic industry. The suggested efficient energy conservation included painting the factory wall panels white or light colors, using electrical ballast, replacing the aging boiler with a new one, replacing lower efficiency lighting with more energy-saving types, and providing electronic control to save daytime power waste for lighting.

2.3 Summary of Literature Review

The following findings are drawn from the researched literature:

- The world's highest energy-intensive industries are those involved in manufacturing and processing.
- Models of mass and energy balance are created for evaluating an industry's thermal performance.
- Energy consumption is much higher.
- Recovering waste heat from a beverage company has the potential for reducing its consumption of energy.

CHAPTER 3

MATERIALS AND METHODS

3.1 Method of the Study

The following are methods for energy analysis in Coca Cola Beverages Africa Company

The energy analysis is conducted at Coca Cola Beverages Africa. The company owns a different type of equipment, including air compressors, chillers, steam boilers, and processing machines. Massive electric transformers and diesel fuel are the main sources of electricity. Temperature, electrical readings, and flow rates were measured using portable test instruments such as the thermocouple flow meter, power analyzer, digital tachometer and multimeter. Extensive data gathering was conducted during the preliminary data collecting phase utilizing a variety of techniques, including measurements and observation. This is accomplished by seeing the company's headquarters, labs, and operational machinery. Via observation and interviews, data on common electrical equipment was gathered. The staff member in charge was approached to retrieve the power bill. A power analyzer was used to measure the appliances' power usage. Boiler analyzer is used to measure ambient temperature, flue gas temperature and percentage of (O_2, CO, CO_2). Key facility staff members were questioned during the preliminary audit to find out about the project's objectives, rules and regulations, team members' roles and duties, and the expected activities of the project. The primary locations for energy utilization were disclosed during the facility tour. We looked at the records that were available about substantial usage.

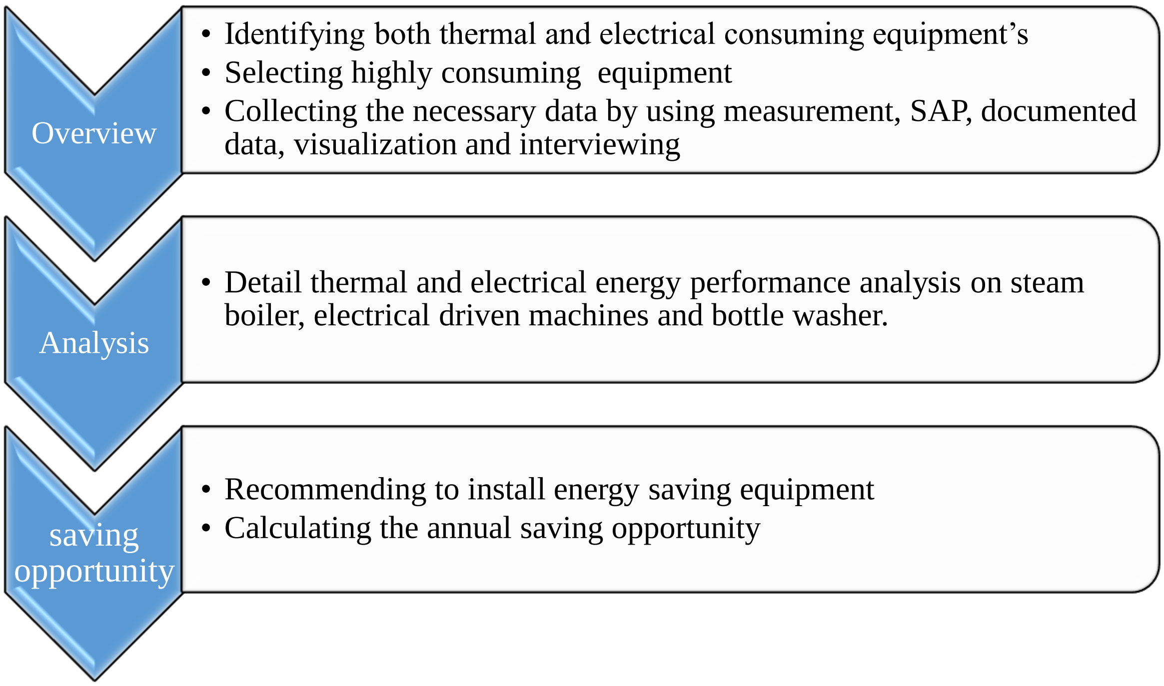


Figure 3.1 Methodology

3.2 Machineries

3.2.1 Polyethylene Terephthalate (PET) Line

Blow-molded into single-use beverage bottles and made into fibers for permanent-press textiles, polyethylene terephthalate, or PETE, is a tough, stiff synthetic fiber and resin that belongs to the polyester group of polymers.

Figure 3.2 Formation of plastic bottle (resin, preform and plastic bottle)

Blow Molding Machine

A manufacturing technique called blow molding is used to shape and melt hollow plastic components together. The first step in the blow molding process is to heat the plastic to soften it and form it into a parison, which is a tube-shaped piece of plastic with a hole at one end that can be filled with compressed air at a pressure of around 40 bar. The plastic is then forced out to fit the mold by the air pressure. The mold opens and the part goes out to the filer once the plastic has cooled and solidified. The mold's channels for water enhance cooling.

Figure 3.3 Blow molding machine

Filling to PET Bottles and Capping Machine

The bottle is pressurized and then carbonated soft drink pours to a valve through a tube. The valve incorporates an inductive flow meter to scan the flow of drink and passes on the impulses to the control system. Once the quantity of impulses is recorded, the flow meter shuts the filling valve. Capping machines are used to cap the bottles filled with material.

Figure 3.4 Plastic bottle filling machine

Labeling Machine

The plastic bottle is fed to the labeling machine at a constant speed on the conveyor. Initially, the bottle is labeled by keeping it on the round bottle labeling machine at a dedicated speed from the conveyor of the machine.

Figure 3.5 Labeling machine

Date Coders

Machines known as "date coders" place dates to products, labels, and packaging. A product's expiration date can also be determined by the date of production.

3.2.2 Returnable Glass Bottle (RGB) Line

There are three line with capacity of Fanta (line one) 26,000 bottle/ hour coca cola (line three) 36,000 bottle/ hour and Sprite (line five) 48,000 bottle/ hour.

Figure 3.6 Three RGB production line (line one, three and five)

Bottle Washing Machine

There are different stages to the cleaning cycle. Prior to washing the bottles are turned upside down immediately following the in feed region to allow the loose dirt particles and liquid residues to fall out of the bottles. The machine collects and releases the residuals in distinct portions. A sieve-belt conveyor system designed to remove solid dirt particles from the machine, including straws, cigarettes, and insects. This sieve-belt also functions as a wastewater filter. An internal jetting pipe is situated behind the dirt removal section in order to expeditiously remove any remaining dirt particles from inside the bottles. After that, bottles are immersed and filled with heated water. Until the bottles are turned upside down in the next jet segment, water is still inside of them. After passing through a sieve-belt filter, the water that runs out returns to the pre-soak. This is the first time that the bottles have been turned upside down, causing debris and shattered glass to gather in the tank's lowest section. The bottles are then transferred to the heat recovery immersion bath, where heat is transferred from the cooling zone without any water mixing, after being pre-rinsed using a series of internal sprayers and exterior showers. Using the remaining heat of the water from the rinsing zone, the temperature is progressively raised in this zone.

After the bottles are cleaned, they are brought to the actual washing area, which is filled with caustic solution. Three crucial steps are involved in bottle washing: first, the bottle is submerged in the soak, where the caustic action of the soda and the high temperature attack the dirt chemically; second, the bottle is emptied to remove the dissolved dirt and the used solution; and third, the internal jet's mechanical action removes the chemically attacked dirt, allowing the remaining dirt to come into direct contact with the detergent solution of the subsequent soak. After the bottles have been rinsed, proceed to the rinsing zone, which typically consists of a few spraying and immersion zones. Here, customized sets of sprayers are used to remove the detergent solution from the bottles and the carrier beams while also progressively lowering the temperature. After that, the pre-washing zone receives all of the rinse water. Each spraying zone has an exterior shower and a series of high-pressure interior sprays. A last injection of fresh water is made prior to the bottles being released, and the bottle is placed onto the conveyor belt by the unloading system once enough time has elapsed for it to drop off.

Figure 3.7 Bottle washing machine

Carbonated Soft Drink Filling Machine and Capping Machine

The carbonated soft drink pours down from the filler tank into the bottle. In the meantime, air from the soft drink bottle is eliminated with the help of an air tube. Once the level of soft drink in the bottle arrives at the nozzle opening of an air tube, the filling is terminated.

Figure 3.8 RGB filling machine

3.3 Production Process of RGB and PET Line

Process flow of Poly Ethyl Terephthalate (PET) line

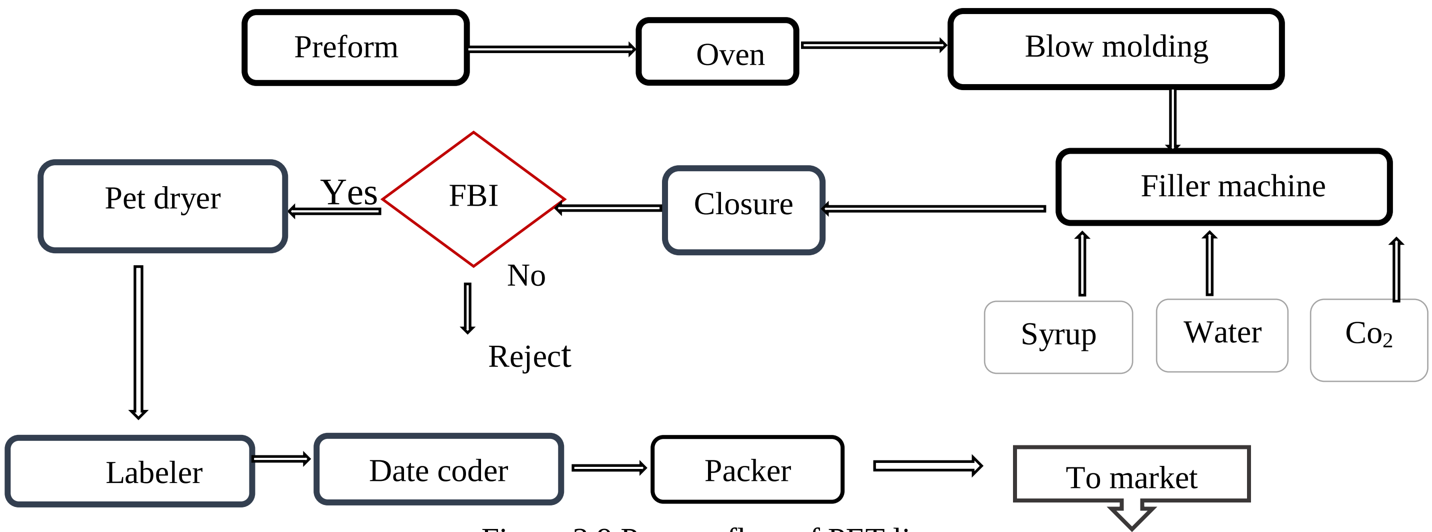


Figure 3.9 Process flow of PET line

Returnable Glass Bottle line work flow

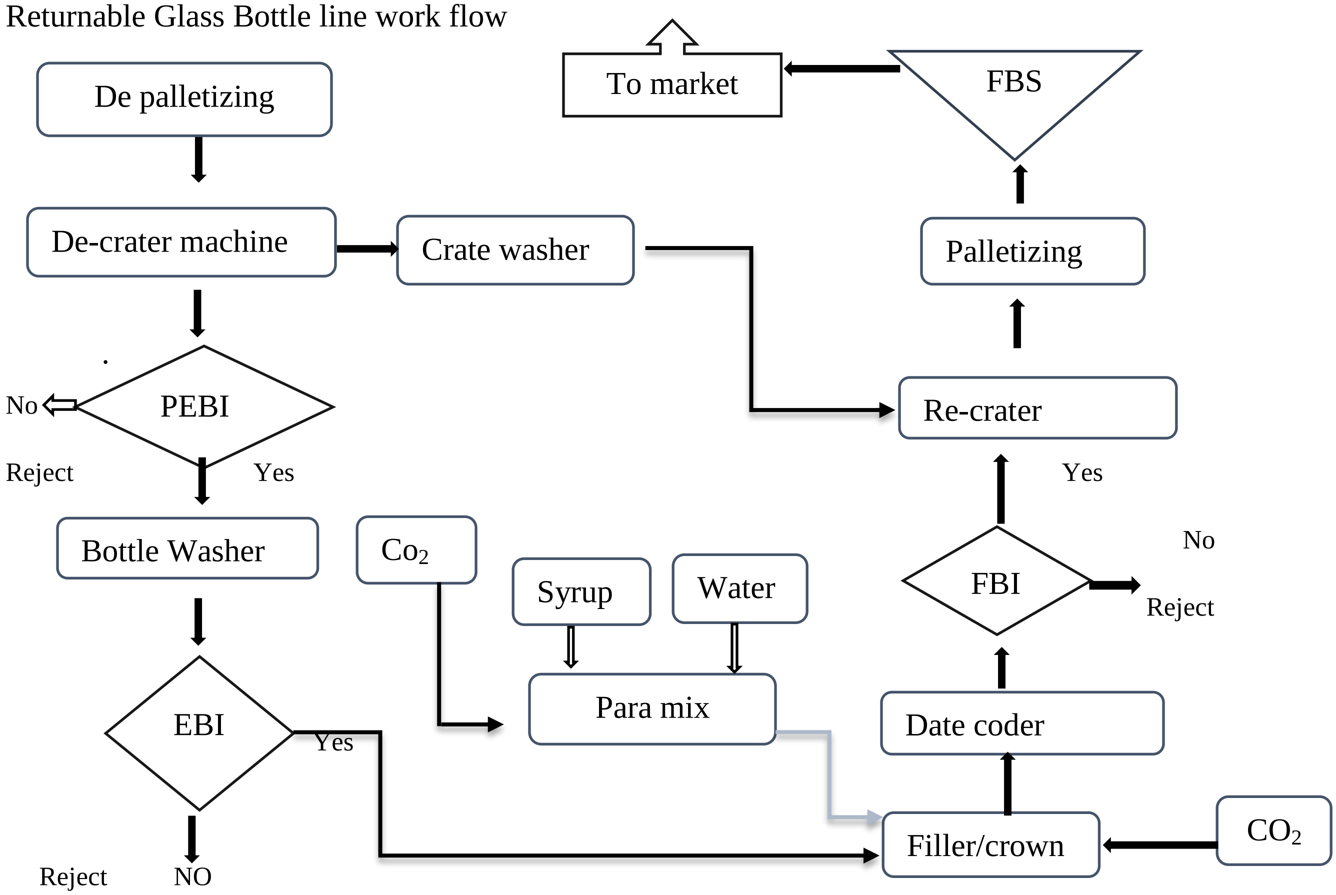


Figure 3.10 Process flow of RGB line

3.4 Thermal Energy

The steam boiler, often known as the steam generator, is typically a closed vessel constructed of steel. In a steam boiler, heat is used for converting water into steam. Coal, oil, and gas are major fuels used in boilers to produce heat.

The company fuel consumption data

The following data extracted from SAP and describe the company fuel demand of the year 2021 and 2023.

Table 3.1 The company fuel consumption and cost review for 2021 and 2022 G.C

	Diesel Fuel quantity in Litter		Diesel Fuel cost in ETB (Million)	
Month	2021	2022	2021	2022
Jan	126,993	122,708	2.5	3.56
Feb	123,263	111,473	2.77	3.23
Mar	135,644	147,027	3.18	4.28
Apr	132,669	133,292	3.1	3.88
May	115,169	140,377	2.69	4.37
Jun	115,320	151,785	2.69	5.41
Jul	118,097	129,394	2.76	5.57
Aug	119,579	132,823	2.79	6.53
Sep	101,446	126,258	2.37	6.23
Oct	119,181	114,909	2.78	6.26
Nov	119,570	98,683	2.79	5.91
Dec	146,851	116,739	3.88	7.01

The fuel consumption is different from month to month and can be visualized as follow

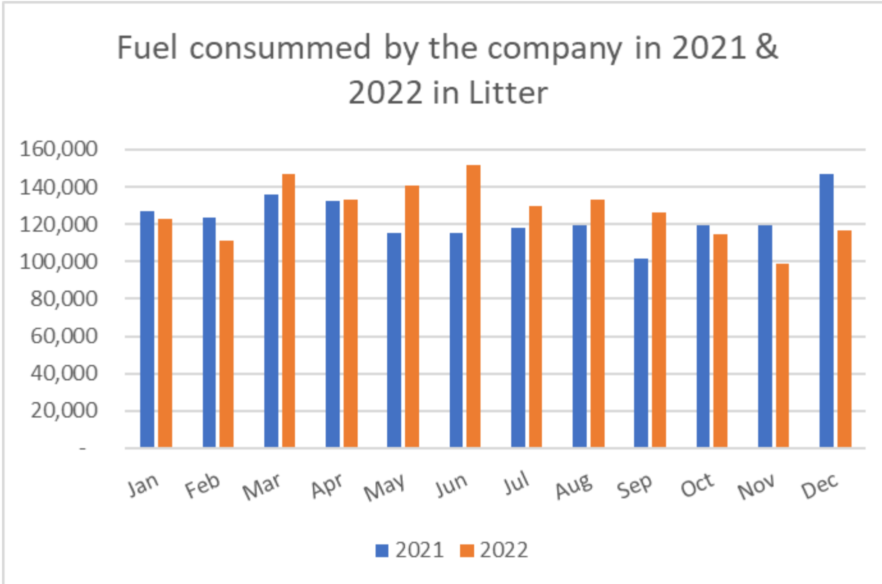


Figure 3.11 Fuel consumption of the company for two years

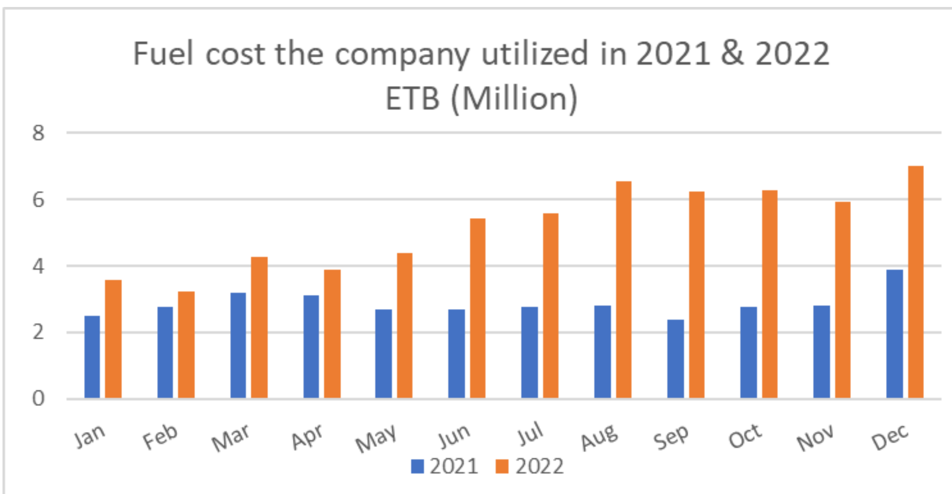


Figure 3.12 Fuel cost of the company for two years in million

3.5 Electrical Energy

Electrical energy is main source of energy for Beverage Industry- a case of Coca Cola Beverages Africa. Power supplied from EEP is 15kv and change to 400v using step down transformer. It can be categorized in to main three sections for bottling of the products.

- Utility
- Production process
- Lighting

The electrical power consumption in the utility section is due to the chiller pump motor, boiler pump motor, and conveyor motor; in the entire production process, the primary energy consuming equipment is the blow mold machine, bottle washing machine, filler, air compressor, and water chiller machines.

3.6 Air Compressors

Air compressors are used in many different industries to provide process needs, power pneumatic tools and equipment, and meet diagnostic requirements. Due to its ease of generation and utilization, compressed air finds extensive application in businesses and the service industry. Compressed air is used in most industrial facilities to create a variety of commodities. In the Coca-Cola Company's instance, pressurized air is utilized to run several pneumatic systems, a glass washer, and blow molding machines. It may be categorized according to the compressed air capacity (low pressure and high pressure) and the compression mechanism (screw, rotary, and piston).

Low pressure compressor (oil free and oil injected): - Oil is used to sink the air by its high-density property, for lubrication and cooling purpose and to resist corrosion due to impurities, but for oil free compressor there is no oil separator since the oil has no contact with the air. It has the following part,

- Air filter: - used for air suction and filtration.
- Element: - where air is permitted to the compressor and compression is performed.
- Unloader: - by using solenoid valve it closes the air intake when the maximum pressure is achieved.
- Separator: - separate oil and air by using their density difference.
- Oil filter: - clean oil from any dirty materials.
- Thermostat: - to control the flow of oil to the condenser plate by monitoring its temperature
- Condenser plate: - heat exchanger for both oil and air cooling.
- Fan: - air suction to condense air and fuel.
- Dryer: - to dry the air by using refrigerant gas.
- Drainer: - exhaust moisture of air from the condensate plate and the drier.

Figure 3.13 Low pressure compressor

High pressure compressor: - Piston type compressor with a capacity of 40 bar. It has one crank shaft driven by a motor using belt pulley mechanism and it drives one vertical and two horizontal piston rod. It has three stages,

- 1st stage – produce 4 bar with vertical piston rod
- 2nd stage - produce 14 bar with horizontal piston rod
- 3rd stage - produce 40 bar with horizontal piston rod

Figure 3.14 High pressure compressor

3.7 Water Chillers' Utility System

Chillers are used to provide chilled water used in production lines to cool the drinks. This is performed by using refrigerant gas (R134a) and cooling water or air. There are two types of chillers their basic difference is the mechanism they use to cool the refrigerant gas (condenser); water cooled and air cooled. Each has a compressor, condenser, evaporator, and expansion (throttling) valve. The compressor compresses the refrigerant gas (vapor compression), increasing its temperature and pressure; the condenser cools down the refrigerant gas using low-temperature air or water. The refrigerant gas at low temperature and high pressure enters expansion (throttle) valve in order to increase area of contact by lowering its pressure. In the evaporator the refrigerant gas and the chiller water exchanges heat.

- ❖ Air cooled chiller: - is well ventilated by using air directly, fan is used to suck the warm air. Sensors are employed to control pressure and temperature throughout the system. Especially temperature of chiller water at the evaporator outlet.

Figure 3.15 Air cooled chiller

- ❖ Water cooled chillers: - uses cooled water in a condenser coming from cooling tower, fan is used cool the cooling water and its level is currently controlled by mechanical control valve. The level should be controlled because high rate of over flow causes low flow rate of cooling water to the condenser. Cycle of cooling and chiller water is closed but additional make up water is available in case there is leakage or over flow.

Figure 3.16 Water cooled chillers

CHAPTER 4

ENERGY ANALYSIS OF STEAM GENERATION AND DISTRIBUTION SYSTEM

4.1 Steam Generation

Industries utilize boilers to produce steam, which the Coca-Cola Company uses for CIP, bottle washing in RGB lines (to dissolve caustic soda), and other purposes. Boilers at the industrial level primarily come in two varieties: fire tube and water tube. The primary distinction between both is that in a fire tube boiler, hot flue gas goes through tubes encircled by water (the water is boiled in the shell); with a water tube boiler, this is not the case. Fire tube boilers are ideal for applications requiring higher consumption, whereas water tube boilers are effective and excellent for applications requiring lower supply. There is fire in tube boiler with a capacity of generating 8 ton steam per hour with minimum 5.5 bar and maximum of 8 bar pressure. This is done based on the very basic relationship of pressure and temperature, pressure increase with the increase in temperature, so condensate water at 65ºC - 80ºC from condensate tank is pumped (using centrifugal pump) to boiler. In the boiler the because of the heat induced in three stages, the temperature of the water raised to 175ºC to produce steam at required pressure. Air and fuel supply is governed by two servo motors and their mixture is calculated by PID (proportion integrate derivative). And photo cell sensor sends signal to ignition coil to create spark and burn the fuel. There is fan to supply air and nozzle to spray the fuel at the burner side of boiler.

Two types of water in combination are used for boiler:

- condensate water: - is a steam that condense after performing a required task in production line, it is reserved in a condensate reservoir found at every line before coming to condenser tank to mix with soft water. 65%
- soft water: - is a treated water provided from water treatment as a makeup water (additional 35% water), Is further heated by using water from the boiler its self to save energy, and treated by anti-scalant to avoid scaling and oxygen scavenger is applied to trap oxygen from their mixture to eliminate corrosion.

TDS and conductivity of the boiler water should be checked frequently and blow down water from boiler should be carried out to control the TDS.

Figure 4.1Company Boiler

4.2 Causes of Heat Loss in Steam Boilers

The proper burning of the fuel, the effectiveness of heat transfer, operation, and maintenance all affect boiler efficiency. The percentage of heat input that is effectively used to produce steam is known as a boiler's thermal efficiency.

The determination of boiler efficiency can be performed through two ways: -

1. Direct Method.
2. Indirect Method.

Direct method:

The straightforward method makes calculating boiler efficiency simple. The boiler efficiency is determined by dividing the total heat output by the heat intake.

Boiler Efficiency = Heat output / Heat Input X 100.

Indirect method:

Another name for indirect efficiency is the heat loss efficiency computation technique. This method calculates efficiency by deducting the heat loss fraction from 100. The ASME PTC-4-1 standard is used to calculate boiler efficiency indirectly. Blow down loss is not taken into account in the efficiency evaluation procedure by the standards.

Indirect boiler efficiency = 100 – (1 +2 + 3 + 4 + 5 + 6)

Were,

1. Percentage heat loss due to dry flue gas (sensible heat)
2. Percentage heat loss due to evaporation of water formed due to hydrogen in fuel (H_2)
3. Percentage heat loss due to evaporation of moisture present in fuel (H_2O)
4. Percentage heat loss due to moisture present in air (H_2O)
5. Heat loss due to incomplete combustion (CO)
6. Heat loss due to radiation and convection

Using the indirect approach, all boiler losses were calculated to calculate the boiler efficiency (Lahijani et.al., 2017); (Harim et.al., 2008); (Barma et.al., 2017); (Virendra et.al., 2013); (Sachin et.al., 2014). Interestingly, there's a correlation between these losses and gasoline use. It was noted that the plant had two boilers, one of which was operating and the other as a backup. The research conducted an independent evaluation of the primary operating boiler's performance test to ascertain the likelihood of losses happening and possible energy savings

To calculate the boiler losses, the extra air supplied and the theoretical (stoichiometric) air fuel ratio were established. They were approximated using the measured values by means of (Lahijani et.al., 2017); (Sachin et.al., 2014).

- Theoretical air required for combustion

$$RA = \left[\left(11.6 * C\right) + \left\{ 34.8 * \left(H_2 - O_2/8 \right) \right\} + \left(4.35 * S\right) \right] / 100 \quad \text{(Sachin et.al., 2014)} \qquad (4.1)$$

- Excess air required for combustion

$$EA = \frac{\%O_2}{21 - \%O_2} * 100 \quad \text{(Sachin et.al., 2014)} \qquad (4.2)$$

- Actual mass of air supplied/ kg of fuel

$$ASS = \left(1 + EA/100\right) * \text{ theoretical air} \qquad (4.3)$$

The next section addressed the different losses connected to boiler operation. (Lahijani et.al., 2017), (Sachin et.al., 2014).

4.3 Fuel Consumption and Heat Output

The amount of fuel consumed, as well as the stoichiometric and excess air input for combustion, determine the heat input to various systems. If the output of the combustion process has to be determined, the loss method was used to estimate the efficiency of combustion, and the fuel analysis and average oxygen content in the flue gases were used to determine the quantity of excess and stoichiometric air.

$$Q_{in} = \dot{m}_f * GCV * \eta_b \qquad (4.4)$$

Where Q_{in} = Heat input to dryer

$\dot{m}_f$ = fuel Consumption

GCV = calorific value of the fuel

η_b = thermal efficiency of combustion

4.4 Energy Performance Assessment of Fire Tube Boiler

The efficiency of the hot water boiler greatly impacts heating, which is linked to energy savings. Thus, it is crucial to reduce heat losses in the hot water boiler and increase heat transmission to the water. It is essential to identify potential energy waste sources in order to maximize the performance of a hot water boiler facility.

In order to calculate the efficiency and performance of the hot water boiler, the following attributes were measured.

Flue gas analysis

- Percentage of CO_2 or O_2 in flue gas
- Percentage of CO in flue gas
- Temperature of flue gas

Temperature measurements for

- Flue gas
- Hot water
- Makeup water
- Fuel
- Heat loss due to dry flue gas

The sensible thermal energy lost in flue gas as a result of temperature changes is known as "dry flue gas loss."

$$L_1 = \frac{m \times C_p \times \left(T_f - T_a\right)}{GCV \text{ of fuel}} \times 100 \text{ (Lahijani et.al., 2017)} \qquad (4.5)$$

Where L_1 = percentage heat loss due to dry flue gas
m = mass of dry flue gas in kg/kg of fuel
C_p =Specific heat of flue gas in kJ/kg
T_f = Flue gas temperature in $°C$
T_a = Ambient temperature in $°C$
GCV = Calorific value of the fuel

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

= Combustion products from fuel: CO_2 +SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas.

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

The losses due from water vapor generated by hydrogen in fuel, moisture in fuel, and air during burning were not included in the dry flue gas loss since they were evaluated separately as a wet flue gas loss.

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

Heat is lost during hydrogen combustion. This is because water is the byproduct of combustion. Once more, this water is transformed into steam, which releases the heat's latent energy.

$$L_2 = \frac{9 \times H_2 \times \left(584 + C_p\left(T_f - T_a\right)\right)}{GCV \text{ of fuel}} \times 100 \text{ (Sachin et.al., 2014)} \qquad (4.6)$$

Where H_2 = kg of hydrogen present in fuel on 1 kg basis
C_p = Specific heat of hot water kJ/kg
T_f = Flue gas temperature in $°C$
T_a = Ambient temperature in $°C$
584 = Latent heat corresponding to partial pressure of water vapor

- Heat loss due to moisture present in fuel (%)

Fuel-borne moisture enters the boiler together with the fuel and exits as a superheated vapor. The sensible heat loss that causes the liquid to boil up compensates up this moisture loss. Heat loss results from the latent heat of moisture evaporation and the amount of superheat needed to raise the steam's temperature to that of exhaust gas. The following formula may be used to determine this loss:

$$L_3 = \frac{M \times \left(584 + C_p\left(T_f - T_a\right)\right)}{GCV \text{ of fuel}} \times 100 \tag{4.7}$$

(Sachin et.al., 2014)

Where M = mass of moisture in fuel in 1 kg basis

C_p = Specific heat of hot water kJ/kg

T_f = Flue gas temperature in $°C$

T_a = Ambient temperature in $°C$

584 = Latent heat corresponding to partial pressure of water vapor

- Heat loss due to moisture present in air (%)

When air that enters travels through the steam boiler, its moisture content is superheated. Considering that the heat travels up the stack, this is seen as a boiler loss. In order to correlate this loss to the quantity of fuel consumed, it requires know the moisture content of the combustion air as well as the amount of air provided per unit mass of fuel burned. The psychometric chart might be used to calculate the mass of water vapor that is contained in air. The Table 5-1 displays the typical values.

Table 4.1Typical values of water vapor that contain air from psychometric chart.

Dry bulb temperature (°C)	Wet bulb temperature (°C)	Relative humidity (%)	kg of water vapor per kg of dry air (value)
20	20	100	0.0148
20	15	50	0.0086
30	21	50	0.012
40	30	50	0.023

$$L_4 = \frac{AAS \times \text{ humidity factor} \times C_p \left(T_f - T_a\right)}{GCV \text{ of fuel}} \times 100 \text{ (Sachin et.al., 2014)} \quad (4.8)$$

- Heat loss due to incomplete combustion (%)

It is possible to combine incomplete combustion products with oxygen and reburn them to release more energy. Such compounds, which were often discovered in the boiler flue gas, include CO, H_2, and other hydrocarbons. The only gas whose concentration is easily measured in a boiler plant test is carbon monoxide

$$L_5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV \text{ of fuel}} \times 100 \quad \text{(Sachin et.al., 2014)} \quad (4.9)$$

Where CO = Volume of CO in flue gas (%)

CO_2 = Actual Volume of CO_2 in flue gas (%)

C = Carbon content kg / kg of fuel

5744 is the heat loss due to partial combustion of the carbon.

- Heat loss due to radiation and convection (%)

One of the additional ways that heat may be wasted from a boiler is through convection and radiation. The boiler casting into the surrounding boiler room is the source of these losses. Generally, depending on the boiler's design and capacity, surface heat losses and other unexplained losses are considered.

The following formula represents the energy loss per unit area of the boiler surface exposed to the surrounding temperature:

$$L_6 = 0.548 \times \left[\left(T_s / 55.55\right)^4 - \left(T_a / 55.55\right)^4\right] + 1.957 \times \left(T_s - T_a\right)^{1.25} \times \sqrt{\left[\left(196.85 V_m + 68.9\right) / 68.9\right]} \quad (4.10)$$

4.4.1 Energy Performance Assessment of Fire Tube Boiler

Flue gas measured data

Table 4.2 Flue gas measured data

Ambient temperature ^{O}C	Flue Gas Analysis			
	O_2%	CO%	CO_2%	Temp of Flue gas ^{O}C
23.5	5.2	0.032	11.8	241

Diesel fuel property

Table 4.3 Diesel fuel property

Property		Diesel
Specific gravity @15°C		0.8329
Flash point		65.5
Ash %		0.01
Moisture content %		0.05
Calorific value (MJ/kg)		46.05
Elemental analysis %	C	81
	H	14
	N	1.97
	O	0.38
	S	0.61

i. The amount of theoretical air needed to burn (Sachin et.al., 2014) using equation (4.1)

$$RA = \left[(11.6*81) + \left\{ 34.8*\left(14 - {0.38}/{8}\right) \right\} + (4.35*0.61) \right] / 100$$
$$= 14.28 \text{ kg of air/ kg of fuel}$$

ii. Excess air required for combustion (Sachin et.al., 2014) using equation (4.2)

$$EA = \frac{5.2}{21 - 5.2} * 100$$
$$= 32.91\%$$

iii. Actual mass of air supplied per kilogram of fuel using equation (4.3)

$$ASS = \left(1 + 32.91/100\right) * 14.28$$
$$= 18.98 \text{ kg/kg of fuel}$$

Actual mass of dry flue gas m

M= Mass of CO_2 +Mass of N_2 contain in the fuel + Mass of N_2 in the combustion air supplied + Mass of oxygen in flue gas

$$m = (C*44/12) + \left[(N_2/100) + (Actual \text{ mass of air } * 77/100)\right] + \left[(Actual \text{ mass of air} - Theoretical \text{ air}) * 23/100\right]$$
$$= (0.81*44/12) + \left[0/100 + (18.98*77/100)\right] + \left[(18.98 - 14.28)*23/100\right]$$
$$= 18.67 \text{ kg/kg of fuel}$$

The next section addressed the different losses connected to boiler performance. (Lahijani et.al., 2017) (Sachin et.al., 2014).

1) Heat loss due to dry flue gas

The heat loss due to dry flue gas is calculated using equation (4.5)

$$L_1 = \frac{18.67 \times 1 \times \left(241 - 23.5\right)}{46050} \times 100$$
$$= 8.818 \ \%$$

$$\dot{Q} = \dot{m}_{flue} * C_P * (T_{flue} - T_a) \quad \text{(Gebremariyam, 2009)} \qquad (4.11)$$

where

T_{flue} - Flue gas temperature = 241 ^{o}C

T_a - Ambient temperature =23.5 ^{o}C

C_p - Specific heat capacity of flue gas =1.35 $\frac{\text{kJ}}{\text{kg k}^{O}}$

$\dot{m}_{flue}$ - Mass flow rate of dry flue gas

$$\dot{m}_{flue} = m_{fuel} * \dot{m}_f$$
$$= 0.0635\, kg/s * 18.67\, kg\ of\ \ dry\ flue\ gas/kg\ of\ \ fuel$$
$$= 1.185\, kg_{dry\ \text{flue gas}}/s$$

Energy loss due to dry flue gas is:

$$\dot{Q} = 1.185 * 1.35 * (241 - 23.5)$$
$$= 347.945 kW$$

2) Heat loss due to evaporation of water formed due to H_2 fuel

Water is generated when the hydrogen in the combustion chamber when fuel combines with oxygen during burning. Some of the energy released during the combustion process is removed by the water that formed.

$$L_2 = \frac{9 \times 0.14 \times \left(584 + 1\left(241 - 23.5\right)\right)}{46050} \times 100$$
$$= 2.19\ \%$$

Equation (4.6) can be used to determine the energy loss caused by the presence of hydrogen in the combustion chamber.

$$Q_{H_2} = (M)_{H_2O} * (\dot{m}_f) * \left[h_{fg@25^oC} + C_P (T_f - T_a) \right] \quad \text{(Gebremariyam, 2009)} \qquad (4.12)$$

where

$\dot{m}_f$ - Mass flow rate of fuel =0.0635 kg s

M_{H_2O} - Mass of water per kg of fuel = 1.08

$h_{fg@25^oC}$ - Enthalpy of water = 2441.12 kJ/kg

C_p - Specific heat capacity = 1.88 kJ $kJ/kg\ ^Ok$

T_{flue} - Flue gas temperature = 241 ^oC

T_{amb} -Ambient temperature =23.5 ^oC

$$Q_{H_2} = 1.08 * 0.0635 * [2441.12 + 1.88 * (241 - 23.5)]$$
$$= 195.45 kW$$

3) Heat loss due to moisture present in fuel

It is calculated using equation (4.7)

$$L_3 = \frac{0.05 \times (584 + 4.187(241 - 23.5))}{46050} \times 100$$
$$= 0.16\ \%$$

Because the burning fuel contains moisture, water will develop during the combustion process. A portion of the energy released during the combustion process is removed by the water that forms. This energy loss from the furnace oil's moisture content is calculated using:

$$Q_M = (M) * (\dot{m}_f) * \left[h_{fg@25^oC} + C_P (T_{flue} - T_{amb}) \right] \quad \text{(Gebremariyam, 2009)} \qquad (4.13)$$

where

$\dot{m}_f$ - Mass flow rate of fuel =0.0635 kg s

M - Moisture in fuel = 0.5%

$h_{fg@25^oC}$ - Enthalpy of water = 2441.12 kJ/kg

C_p - Specific heat capacity = 1.88 kJ $kJ/kg\ ^oK$

T_{flue} - Flue gas temperature = 241 ^oC

T_{amb} -Ambient temperature =23.5 ^oC

Using Equation (5.13) and the previously mentioned data as an alternative, the heat loss from water evaporation resulting from fuel hydrogen formation is:

$$Q_M = 0.005 * 0.0635 * [2441.12 + 1.88 * (241 - 23.5)]$$
$$= 0.904 kW$$

4) Heat loss due to moisture present in air

Moisture is present in the air uses for burning under typical circumstances. The moisture content of the air causes energy loss that is comparable to the previously mentioned moisture content of burner.

It is estimated through equation (5.8);

$$L_4 = \frac{18.96\times\ 0.0124\times1\left(241-23.5\right)}{46050}\times100$$
$$=0.11\ \%$$

Given the moisture content of the combustion air, the energy lost is as follows:

$$Q_{moi} = AAS*\gamma_A*(\dot{m}_f)\left[C_p(T_f - T_a)\right]$$ (Gebremariyam, 2009) (4.14)

where

AAS - Actual air supplied 18.98 kg of air / kg of fuel

γ_A = 0.0124 kg of H_2O/kg of dry air

Substituting the above data in Equation (4.14) the energy loss due moisture content in the combustion air is given by:

$$Q_{moi} = 18.98 * 0.0124 * 0.0635 * \left[1.88\, {kJ}\big/{kg^oK}\,(241-23.5)\right]$$
$$= 6.11kW$$

5) Heat loss due to incomplete combustion (%)

Under typical conditions, moisture is present in the air needed for combustion. The moisture content of the air causes energy loss equivalent to that of the boiler described above..

It is determined through equation (4.9)

$$L_5 = \frac{0.032\times0.81}{0.032+0.118}\times\frac{5744}{46050}\times100$$
$$=2.155\ \%$$

The energy loss due to incomplete combustion is given by

$$Q = m_{ic}*67636$$ (Gebremariyam, 2009) (4.15)

Where

heat of combustion of CO = 67636 kCal/ kg mole and

$$m_{ic} = \frac{\%CO}{100*22.4} * specific\ volume\ of\ \ exit\ gases$$

By estimating 0.1% CO at the outlet,

$$m_{ic} = \frac{0.1}{100*22.4} *1.421 = 6.344X10^{-5} kg\ mol / kg$$

$$Q = 6.344X10^{-5} kg\ mol / kg * 67636\ kCal /\ kg\ mole$$
$$= 4.2906 kCal /\ kg = \text{ 17.96kJ/kg}$$

6) Heat loss due to radiation and convection (%)

Energy from the boiler surface is lost to the wind through convection when the wind blows over it. Furthermore, radiation energy loss occurs as a result of the temperature differential between the boiler surface and the surrounding air.

i. Heat loss due to radiation and convection from boiler cylinder surface at measured surface temperature of 66°C.

$$L_{cs} = 0.548 \times \left[\left(339/55.55 \right)^4 - \left(296.5/55.55 \right)^4 \right] + 1.957 \times (339 - 296.5)^{1.25} \times \sqrt{\left[(196.85*2.5+68.9)/68.9 \right]}$$
$$= 315.27W / m^2 \ + 605.98\text{W/m}^2$$
$$= 921.25\text{W/m}^2,\ \text{where } A_c = \pi DL = 14.25 m^2$$
$$= 13.127 kW$$
$$= \frac{13.127kW}{GCV * \dot{m}_{fuel}} *100 = 1.52\ \%$$

ii. Heat loss due to radiation and convection from boiler front surface at measured surface temperature of 95°C.

$$L_f = 0.548 \times \left[\left(368 / 55.55 \right)^4 - \left(296.5 / 55.55 \right)^4 \right] + 1.957 \times \left(368 - 296.5 \right)^{1.25} \times \sqrt{\left[\left(196.85 * 2.5 + 68.9 \right) / 68.9 \right]}$$

$$= 610.67 W/m^2 \ +1161.06 \mathrm{W/m^2}$$

$$= 1771.73 \mathrm{W/m^2}, \text{ where } \mathrm{A}_f = \frac{\pi D^2}{4} = 1.45 m^2$$

$$= 2.57 kW$$

$$= \frac{2.57 kW}{GCV * \dot{m}_{fuel}} * 100 = 0.0296 \ \%$$

iii. Heat loss due to radiation and convection from boiler bottom surface at measured surface temperature of 70°C.

$$L_b = 0.548 \times \left[\left(343 / 55.55 \right)^4 - \left(296.5 / 55.55 \right)^4 \right] + 1.957 \times \left(343 - 296.5 \right)^{1.25} \times \sqrt{\left[\left(196.85 * 2.5 + 68.9 \right) / 68.9 \right]}$$

$$= 351.785 W/m^2 \ +678.091 \mathrm{W/m^2}$$

$$= 1029.876 \mathrm{W/m^2}, \text{ where } \mathrm{A}_b = 1.32 m^2$$

$$= 1.79 kW$$

$$= \frac{1.79 kW}{GCV * \dot{m}_{fuel}} * 100 = 0.206 \ \%$$

L_6 =1.52%+ 0.0296%+ 0.206%= 1.7556%

The energy loss due to convection and radiation in watt per unit area of the boiler surface exposed to the ambient temperature condition is given by equation (4.16)

This type of loss is estimated through equation (4.10)

$$Q_{(i)s} = \left\{ 0.548\left[(T_{(i)s}/55.55)^4 - (T_{(i)a}/55.55)^4 \right] + 1.957(T_{(i)s} - T_{(i)a})^{1.25} \sqrt{\frac{196.85V_s + 68.9}{68.9}} \right\} \frac{w}{m^2} * S_{(i)A} \quad (4.16)$$

where

T_s - Surface temperature for front, cylindrical and back is 368 ^{O}k, 339 ^{O}k and 343 ^{O}k respectively.

V- Wind velocity = 2.56 m/s

Ta- Local ambient temperature for front, cylindrical and back is 305 ^{O}k, 299 ^{O}k and 300.5 ^{O}k respectively.

S_A - Surface area for front, cylindrical and back is 1.45m^2 , 14.25m^2 and 2.41m^2 respectively.

Substituting the values of the above data in Equation (4.16) the total heat loss due to convection and radiation is:

$$Q_{(i)s} = Q_{Front} + Q_{Cylinder} + Q_{Back} \quad (4.17)$$

$$\begin{aligned} Q_{(i)s} &= 3.21kW + 1.1kW + 0.46kW \\ &= 4.77kW \end{aligned}$$

Once the size of each of the aforementioned losses has been determined, the boiler's efficiency may be found using a straightforward heat balance. The difference between the energy input into the boiler and the computed heat losses is the efficiency.

$$\begin{aligned} \eta_{boiler} &= 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6) \\ &= 100 - (8.818 + 2.19 + 0.16 + 0.11 + 2.155 + 1.7556) \\ &= 84.81\% \end{aligned}$$

4.5 The Heat Carried Away by the Steam

Steam is a significant source of energy output. To calculate the amount of heat energy transported away by steam, multiply the amount of steam produced per second by the enthalpy. The enthalpy is supplied in a steam table, and flow rate, temperature, and pressure can be measured using gauges installed on the boiler. The output energy could be derived using equation (4.18).

$$Q_S = \dot{m}_s * h_{gs} \quad (4.18)$$

where

$\dot{m}_s$ - Mass flow rate of steam =174,179.328 kg / day

h_{gs} -Enthalpy of saturated steam at a temperature of 170 ^{O}C and pressure 8 bar = 2768.3 kJ/kg

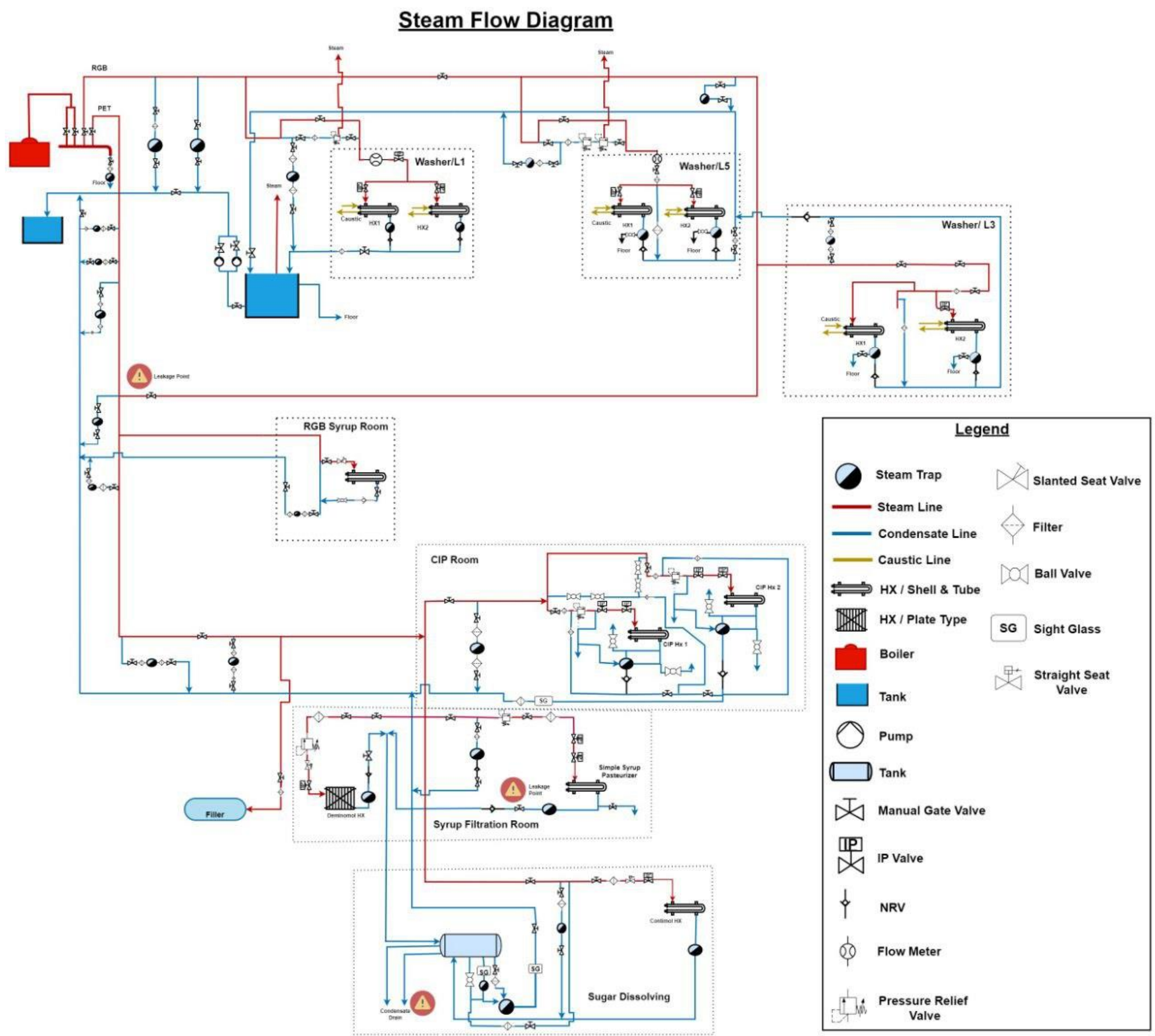
Qs -Heat carried away by the steam

Substituting the value of the above data in Equation (4.18) the heat carried away by the steam is:

$$Q_S = 174{,}179.328\, kg/day * 2768.3\ kJ/kg$$
$$= 5{,}580.798 kW$$

4.6 Description of Steam Distribution System

Steam distribution systems include pipelines, steam traps, condensate return lines, and other equipment such as pumps. The wear and degeneration of this equipment may result in energy waste. Energy management may enhance the system by enhancing insulation, detecting and correcting leaks, maintaining steam traps and pumps, and providing water treatment. The company steam line is drawn by using Edrawmax.



58587]

Figure 4.2 Company steam line

4.6.1 Glass Bottle Washer Thermal Energy Analysis

An automated double-ended bottle washer is used to clean all returnable glass bottles that are brought into the factory. The main panel, which is situated near the bottle infeed area and has all of the necessary operational components and a temperature display. Pre-cleaning, caustic wash, and final rinse are the three separate cleaning and sterilizing processes that are applied to the soiled bottles. During the caustic washing phase, when the extremely soiled and unclean bottles are constantly passed through the washer's three hot caustic soaking chambers (baths 1, 2, and 3), where microorganisms are destroyed by heat and chemical means, effective cleaning takes place. Compared to other alkalis used for washing, caustic soda (NaOH) is more affordable, less prone to heat shock, and has a longer germicidal effect. NaOH assaults glass at a solution temperature of 80 °C, softening its surface and allowing organic materials to dissolve, oil and grease to emulsify, and grime to be removed in suspension.

The First Law of Thermodynamics states that heat input to a system equals heat energy removed from it when no work is performed, kinetic and potential energies are neglected, and a steady state condition is assumed.

$$Q_{in} = Q_{sensible} + Q_{condensate\ return} + Q_{loss} \tag{4.19}$$

$$Q_{sensible} = \dot{m}_{NaOH} * C_{pNaOH} * \left[T_{out} - T_{in}\right]$$

$$Q_{condensate} = \dot{m} * C_{p} * \left[T_{out} - T_{in}\right]$$

$$Q_{latent} = \dot{m} * \left[H_{in} - H_{out}\right]$$

$$\eta = \left(\frac{Q_{sensible} + Q_{condensate} + Q_{latent}}{Q_{in}}\right) * 100$$

C_p of NaOH is drived from (Chase, 1998)

$$C_p = A + Bt + Ct^2 + Dt^3 + E/t^2$$

were A= 88.34725, B= -2.495103 C=-3.013028 D=0.862607 E=0.042216 and

t = temprature(k)/1000

Table 4.4 Three production measured and calculated values

	Line 1				Line 3				Line 5			
	Steam parameter		Caustic data		Steam parameter		Caustic data		Steam parameter		Caustic data	
	in	out	in	out	in	out	in	out	in	out	in	out
Temperature (^oC)	170.42	129	25	80	170.4	129	25	81	170.42	129	25	79
Mass flow rate (kg/s))	0.215		0.146		0.215		0.146		0.215		0.146	
Cp(kJ/kg K)	1.99	4.19	2.196		1.996	4.19	2.196		1.996	4.2	2.196	

The total steam produced by the steam boiler is 5,580.798kWw and the capacity of the washer is 26,000 BPH, 36,000 BPH and 48,000 BPH for line one three and five and , with average energy input 50% for sugar dissolving and 2,790.399 kW is used for 50% for CIP and bottle washer of 11.81 %, 16.36% and 21.818% for line 1, 3 and 5 respectively.

Efficiency of line one bottle washer is calculated by substituting the data from table 4.4 in to question 4.19 with heat energy input of 154.94 Kw,

$$Q_{sensible} = 0.146 * 2.196 * [80 - 25] = 17.634 kW$$
$$Q_{condensate} = 0.215 * 4.19 * [170.42 - 129] = 54.21 kW$$
$$Q_{latent} = 0.215 * [2460.19 kJ / kg - 2257.92 kJ / kg] = 43.488 kW$$
$$\eta = \left(\frac{17.634 + 54.21 + 43.488}{154.94 kW} \right) * 100 = 74.43\%$$

Similarly for bottle washer three with heat energy input of 160.72 kW,

$$Q_{sensible} = 0.146 * 2.196 * [81 - 25] = 17.9544 kW$$
$$Q_{condensate} = 0.215 * 4.19 * [170.42 - 129] = 54.21 kW$$
$$Q_{latent} = 0.215 * [2460.19 kJ / kg - 2257.92 kJ / kg] = 43.488 kW$$
$$\eta = \left(\frac{17.9544 + 54.21 + 43.488}{160.72 kW} \right) * 100 = 71.96\%$$

Finally for bottle washer five, with heat energy input of 168.72 kW,

$$Q_{sensible} = 0.146 * 2.196 * [79 - 25] = 17.313 kW$$
$$Q_{condensate} = 0.215 * 4.19 * [170.42 - 129] = 54.21 kW$$
$$Q_{latent} = 0.215 * [2460.19 kJ / kg - 2257.92 kJ / kg] = 43.488 kW$$
$$\eta = \left(\frac{17.313 + 54.21 + 43.488}{168.72 kW} \right) * 100 = 68.166\%$$

From the above calculation the heat loss can be calculated using question 4.19

$$\begin{aligned} Q_{losses} &= 39.608 kW + 45.0676 kW + 53.709 kW \\ &= 138.3846 kW \end{aligned}$$

Following this, a thorough thermal energy analysis of the production process plant's bottle washer component indicated that 1,212,249.096 kWh of thermal energy were lost annually, and the thermal efficiency of the bottle washer had been determined to be 74.43%, 71.96%, and 68.166% of lines one, three, and five, respectively.

CHAPTER 5

ENERGY ANALYSIS OF ELECTRICAL ENERGY CONSUMING MOTOR

5.1 Analysis of Electrical Motor

Process drives, conveyor systems, and HVAC (heating, ventilation, and air conditioning) systems are just a few of the many uses for motors. Electrical energy is transformed into mechanical energy by an electric motor. Conveyors, pumps, fans, and an air compressor are powered by the motors at East Africa Bottling S.C. The motors used in the plant have rated powers ranging from 0.55kW to 90kW, an efficiency of 0.73 to 0.91, and a power factor of 0.80 to 0.81. Nameplates, voltmeters, clampers, fluid flow meters, control board displays, anemometers, meters, time clocks, local control panels, and observation were among the tools used to gather data in order to assess the energy performance of motors, water pumps, air compressors, and their motors.

Power and energy evaluations are used to make sure the system is sized and run correctly, as well as to examine equipment loads, energy consumption, and operating costs. Circuit voltage (V), amperage or current (I), and power factor are multiplied to determine power. with relation to three-phase systems.

$$Percentage\ loading\ [\%L] = \frac{V_m * I_m}{V_r * I_r} * 100 \tag{5.1}$$

$$Power\ input\ [P_{in}] = \sqrt{3} * V_m * I_m * p.f \tag{5.2}$$

where $v_m = 380V,\ v_r = 400V$

Efficiency of motor is the ratio of a motor's useful mechanical power output to its total electrical power input.

$$\eta = \frac{\text{Rated power}}{\text{power input}} * \text{Load}$$

5.2 Inspection of Available Motor and Data Collection

To calculate the energy performance of manufacturing motors, various motor data were obtained through inspection and testing.

5.2.1 Data Collected by Visual Inspection and Interviews

The following information was obtained during the examination of East Africa Bottling S.C. through visual inspection and interviews. The range of rated power is between 0.55kW to 90Kw, rated power factor between 080 to 0.81, rated efficiency 0.73 to 0.91, services time 6 years to 13 years and operating time 450 hours to 6,336 hours per year.

5.2.2 Energy Performance Evaluation of Motors

It is essential to compute or determine the motor's power factor, motor efficiency, and motor loading in order to assess the energy performance of motors. Since there is a definite correlation between motor efficiency and load, motor loading and efficiency are utilized in this section to assess motor performance. The motors perform best at 75% load and are designed to run at 50% to 100% load. For effective operation and cost savings across the plant, high motor efficiencies and a power factor near to one are preferred. On the other hand, the motor's rated power determines the cutting value when the loading is low.

5.3 Annual Energy Consumption of Driving Electrical Motors

Using the following equation, the yearly energy consumption for standard motors of product processing machines in plant lines and the corresponding production process zones were calculated during this part of the study.

$$AEC = P_{in} * L * h_y \tag{5.3}$$

Where

AEC: Annual energy consumption for electrical motor (kWh)

L: Percentage loading

5.3.1 Borehole Driving Motor

A borehole is a short shaft drilled into the earth, either vertically or horizontally, for drawing water from below. The company has two boreholes to get approximately 16 L/sec.

Table 5.1 Borehole driving motor data

Zone	Rated Power(kW)	η %	Input Electric Power (kW)	Loading (%)
Bore Hole 1&2	30	89	21.5	71.7
	15	89	11.3	75.3
		Av=89%	$\sum P_{in}$=32.8	Av=73.5%

Using equation (5.3), the annual energy consumption of the two boreholes can be estimated as below:

$$\begin{aligned} AEC &= 32.8kW * 0.735 * 8760hr \\ &= 211{,}186.08kWh \end{aligned}$$

Also, the annual electrical energy loss can be calculated by multiplying the annual energy consumption by respective motor efficiency.

$$\begin{aligned} AEL &= 211{,}186.08kWh * 0.11 \\ &= 23{,}230.47kWh \end{aligned}$$

5.3.2 Water Treatment Driving Motor

The water treatment is a process performed in reverse osmosis process. It has two ways where one is made by using direct chemical reactant raw materials and other is by ion exchange process where the hardness of sodium chloride salt is exchanged for an equivalent amount of sodium which contains no hardness properties. The water softening process is available for washing machine, steam boiler, filler machine as well as crate washer machine. The reservoir tank supplies water towards the water treatment section. The formation of treated water that are used for the product component in the syrup room which are going to filler machine begins by the addition of chemical raw materials like chlorine, aluminum sulphate, calcium chloride, and lime inside the water tank is too high. These raw materials are agitated by a motor with a normal frequency speed checked by the chemists during preparation. These chemicals are pushed toward the reaction tank through a thin hose from the storage tanks. The operators ensure the quality of the water by draining a sample through discharging pipes water. The next work process goes to a device called polisher which contains a pressed filter inside it that are used to purify the solid content of the treated water. Finally, the treated water is pushed by a product pump where the valve manifold panel supplies the product water to be dosed with the product component.

Table 5.2 Available driving motor data in water treatment plant

Zone	Rated Power(kW)	η %	input Electric Power (kW)	Loading (%)
Water Trea, Degas	11	91	7.54	68.5
Water Trea, Settler Tank	11	90	7.2	65.5
Water Treat, New, buffer	15	91	11.6	77.3
Water Treatment	1.5	73	0.9	60
Water Treatment	5.5	73	3.92	71.3
Water Treat. Filter	11	91	8.5	77.3
Water Treat.	5.5	73	4.08	74.2
		Av=83.1%	$\sum P_{in}$=43.74	Av=70.6%

Using equation (5.3), the annual energy consumption of water treatment driving motor estimated as:

$$\begin{aligned} AEC &= 43.74kW * 0.706 * 8760hr \\ &= 270,512.65kWh \end{aligned}$$

The annual electrical energy loss also calculated using the average efficiency of 83.1%.

$$\begin{aligned} AEL &= 270,512.65kWh * 0.17 \\ &= 45,987.15kWh \end{aligned}$$

5.3.3 Bottle Washer Electric Motor

An electric motor that is managed by a frequency variator propels the main chain. The gearbox is equipped with heat- and mechanical-safety mechanisms which trip when overloads or abnormalities occur. The operator panel allows for manual control of production speed. Shafts and chains are used to transfer the movement to the worm reduction units, which are mounted on the main shafts. Every gear has a mechanical safety device installed. The gearbox supports the shafts on one side, while a sleeve made of a unique substance supports them on the other. In order to facilitate maintenance, the toothed wheels are attached to the shaft.

Table 5.3 Bottle washer electric driving motor data

Zone	Rated Power(kW)	η %	input Electric Power (kW)	Loading (%)
	5.5	73	3.34	60.7
	5.5	73	3.44	62.5
	7.5	73	5.16	68.8
	4.5	77	2.8	62.2
	4	77	3.26	81.5
	4	77	2.75	68.8
	4	77	2.88	72
	4	77	2.9	72.5
	0.75	77	0.4	53.3
	0.75	73	0.41	54.7
	2.2	73	1.2	54.5
Bottle washer	1.5	79	0.62	41.3
	4	73	2.81	70.3
	7.5	77	5.33	71.1
	7.5	77	5.39	71.9
	1	73	0.41	41
	1	73	0.4	40
	1	73	0.44	44
	1	73	0.38	38
	1	73	0.36	36
	1.6	73	0.56	35
	5.5	73	3.84	69.8
	11	73	6.7	60.9
		Av=74.6%	$\sum P_{in}$=55.78	Av=57.8%

Using equation (5.3), the annual energy consumption of the two glass bottle washers of the company can be estimated as:

$$AEC = 55.78kW * 0.578 * 8760hr$$
$$= 282,429.76kWh$$

Similarly, the annual electrical energy loss is calculated by average motor efficiency of 74.6%.

$$AEL = 282,429.76kWh * 0.254$$
$$= 71,737.16kWh$$

5.3.4 Glass and Plastic Bottle Filler Driving Machine

The measured data for four filling machine was stated on Table (5.5)

Table 5.4 Bottle filler driving motor data (three RGB line and one PET line)

Zone	Rated Power(kW)	η.%	input Electric Power (kW)	Loading (%)
Bottle Filler	5.5	73	3.72	67.6
	1.75	73	0.45	35.6
	1.5	73	0.5	33.3
	0.75	73	0.41	54.7
		Av=73%	∑ Pin=5.08	Av=47.8%

Using equation (5.3), the annual energy consumption of four lines both plastic and glass bottle can be calculated as:

$$AEC = 5.08kW * 0.478 * 8760hr$$
$$= 21,271.38kWh$$

Similarly, the annual electrical energy loss is calculated by using the average motor efficiency of 73%.

$$AEL = 21,271.38kWh * 0.27$$
$$= 5,743.27kWh$$

5.3.5 Plastic Bottle Labeler Driving Motor

The raw and calculated data is given on Table 5.5

Table 5.5 PET line labeling machine motor data

Zone	Rated Power(kW)	η %	input Electric Power (kW)	Loading (%)
Bottle labeler	6.4	73	5.4	84.4
	1.5	73	1.08	72
		Av=73%	∑ Pin=6.48	Av=78.2%

Using equation (5.3), the annual energy consumption of plastic bottle labeling machine motor was estimated as:

$$AEC = 6.48kW * 0.782 * 8760hr$$
$$= 44,390.07kWh$$

Similarly, the annual electrical energy loss is calculated using the average motor efficiency of 73%.

$$AEL = 44,390.07kWh * 0.27$$
$$= 11,985.32kWh$$

5.3.6 RGB Packer and Unpacker Driving Motor

Uncase machines are used frequently in the beverage sector to provide damage-free bottle unpacking from cases onto bottle washing conveyors. Because of their outstanding technological characteristics, case packer machines are highly sought after in the industry. The extra-ordinary case packing machines are made specifically to package bottles automatically in the appropriate cases. These top-notch case packing machines have grippers with a long lifespan and an advanced safety system that guarantees both bottle and human safety.

Table 5.6 RGB packer and unpacker driving motor data

Zone	Rated Power(kW)	η%	input Electric Power (kW)	Loading (%)
Packer	3	73	2.52	84
	1.5	73	1.18	78.7
	1.5	73	1.15	76.7
	1.5	73	1.2	80
	0.75	73	0.54	72
Unpacker	3	73	2.64	88
	1.5	73	0.54	36
	1.5	73	0.53	35.3
		Av=73%	∑ Pin=10.3	Av=68.8%

Using equation (5.3), the annual energy consumption of both packer and unpacker driving motor for glass bottle was estimated as:

$$AEC = 10.3kW * 0.688 * 8760hr$$
$$= 62,076.864kWh$$

Also, the annual electrical energy loss is calculated by the average motor efficiency of 73%.

$$AEL = 62,076.864kWh * 0.27$$
$$= 16,760.75kWh$$

5.3.7 Conveyor Motor System

A common type of mechanical handling equipment for moving products from one location to another is a conveyor system. Applications requiring the transportation of large or heavy goods benefit greatly from the use of conveyors. Conveyor systems are quite popular in the packaging and material handling sectors because they make it possible to move a variety of items quickly and efficiently. Conveying systems come in a variety of forms and are employed based on the particular requirements of various sectors.

Table 5.7 Conveyor motor system measured and calculated data

Zone	Rated Power(kW)	η %	input Electric Power (kW)	Loading (%)
Loader to Unpacker	0.75	73	0.28	37.3
	0.75	73	0.26	34.7
Unpacker to Bottle Washer	1.1	77	0.58	52.7
	1.1	77	0.48	43.6
	1.1	77	0.55	50
	1.5	77	0.47	31.3
	1.5	77	0.56	37.3
Washer to Filler	1.5	79	0.41	27.3
	1.5	79	0.36	24
	1.5	79	0.44	29.3
	1.5	79	0.48	32
	1.5	79	0.52	34.7
	1.5	79	0.58	38.7
	1.5	79	0.52	34.7
	1.5	79	0.48	32
	1.5	79	0.5	33.3
	1.1	77	0.48	43.6
	1.1	77	0.52	47.3
	1.1	77	0.55	50
	1.1	77	0.53	48.2
	1.1	77	0.5	45.5
	1.1	77	0.49	44.5
	1.1	77	0.48	43.6
	1.1	77	0.53	48.2
	1.1	77	0.48	43.6
	1.1	77	0.48	43.6
Filler to Labeler	1.1	77	0.23	20.9
	1.1	77	0.53	48.2
	1.1	77	0.52	47.3
	1.1	77	0.47	42.7
	1.1	77	0.5	45.5
	1.1	77	0.52	47.3
	1.1	77	0.54	49.1
	1.1	77	0.5	45.5
	1.1	77	0.52	47.3

	1.1	77	0.49	44.5
	1.1	77	0.48	43.6
	1.1	77	0.52	47.3
	1.1	77	0.49	44.5
	1.1	77	0.55	50
Labeler to Packer	1.5	77	0.53	35.3
	1.1	77	0.52	47.3
	1.1	77	0.53	48.2
	1.1	77	0.5	45.5
	1.5	79	0.48	32
Packer to Unloader	0.75	73	0.36	48
	0.75	73	0.36	48
	0.75	73	0.41	54.7
	0.75	73	0.44	58.7
	0.75	73	0.4	53.3
	0.75	73	0.4	53.3
	0.75	73	0.42	56
	0.75	73	0.38	50.7
	0.75	73	0.36	48
	0.75	73	0.41	54.7
		Av=76.5%	∑ Pin=25.85	Av=43.42%

Using equation (5.3), the annual energy consumption of different conveyor operating motor was estimated as:

$$AEC = 25.85kW * 0.4342 * 8760hr$$
$$= 98,322.85kWh$$

Also, the annual electrical energy loss is calculated using the average motor efficiency of 76.5%.

$$AEL = 98,322.85kWh * 0.235$$
$$= 23,105.87kWh$$

5.3.8 Boiler Motor Rated and Measured Value

The basic function of this room is boiling water and changes to steam. Steam pressure, oil furnace and height of water level are regulated automatically. Heating transports thermal energy to the water inside the boiler body, which warms and vaporizes the steam, causing the boiler pressure to rise.The saturated steam is transported through pipe to bottle washer, syrup room, crate washer, and CIP machine.

Table 5.8 Boiler pump motor rated and measured values

Zone	Rated Power(kW)	η %	input Electric Power (kW)	Loading (%)
Boiler	4	73	2.5	62.5
	12	73	3.4	28.3
	3	73	1.2	40
		Av=73%	∑ Pin=7.1	Av=43.6%

Using equation (5.3), the annual energy consumption of the boiler pump was estimated as:

$$\begin{aligned} AEC &= 7.1kW * 0.436 * 8760hr \\ &= 27{,}117.46kWh \end{aligned}$$

Also, the annual electrical energy loss is calculated using motor efficiency of 73%.

$$\begin{aligned} AEL &= 27{,}117.46kWh * 0.27 \\ &= 7{,}321.7kWh \end{aligned}$$

In general, comprehensive yearly electrical energy consumption of 105 electrical motors was measured for manufacturing plants on lines 1, 3, 4, and 5, as well as their associated production zones. Finally, main production machine driving motors from borehole to packer utilized 891.9 MWh, boiler driving motors consumed 27.1 MWh, the conveyor motor system consumed 98.3 MWh, and the overall yearly electrical energy consumption was 1,017.3 MWh.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Steam Boiler Heat Balance

The heat balance is an attempt to balance the total energy entering the boiler against departing the system in various ways. It is shown in Figure 6.1 along with the numerous losses that occur throughout the process of creating saturated steam.

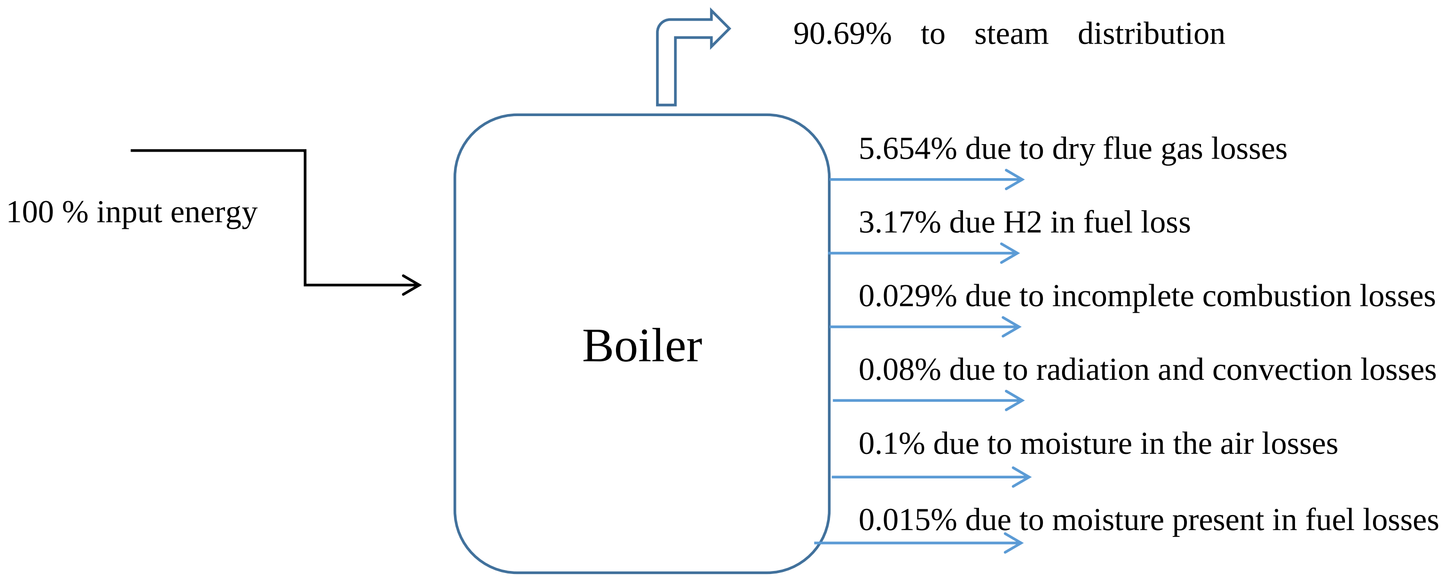


Figure 6.1 Useful Heat and different heat losses mentioned by percentage

6.2 Energy Sankey Diagram of the Boiler

After completing an energy balancing calculation, the Sankey diagram is a very useful tool for depicting the whole input and output energy flow in any type of energy device. The graphical representation of various outputs and losses enables energy managers to effectively prioritize enhancements. The boiler's energy Sankey diagram, produced with the use of the heat balance sheet found in chapter four, is displayed in Figure 6.2.

The accompanying schematic illustration of the boiler shows that about 573.139 kW of heat loss was caused mostly by convection and radiation through the boiler surface, hydrogen in the fuel, and dry flue gas. Additionally, an estimate of the hourly thermal energy loss is 2063.3004MJh. This suggests that around 39.07 million ETB are wasted annually and that approximately 47.99 kg (or 56.706 liters) of diesel are lost per hour.

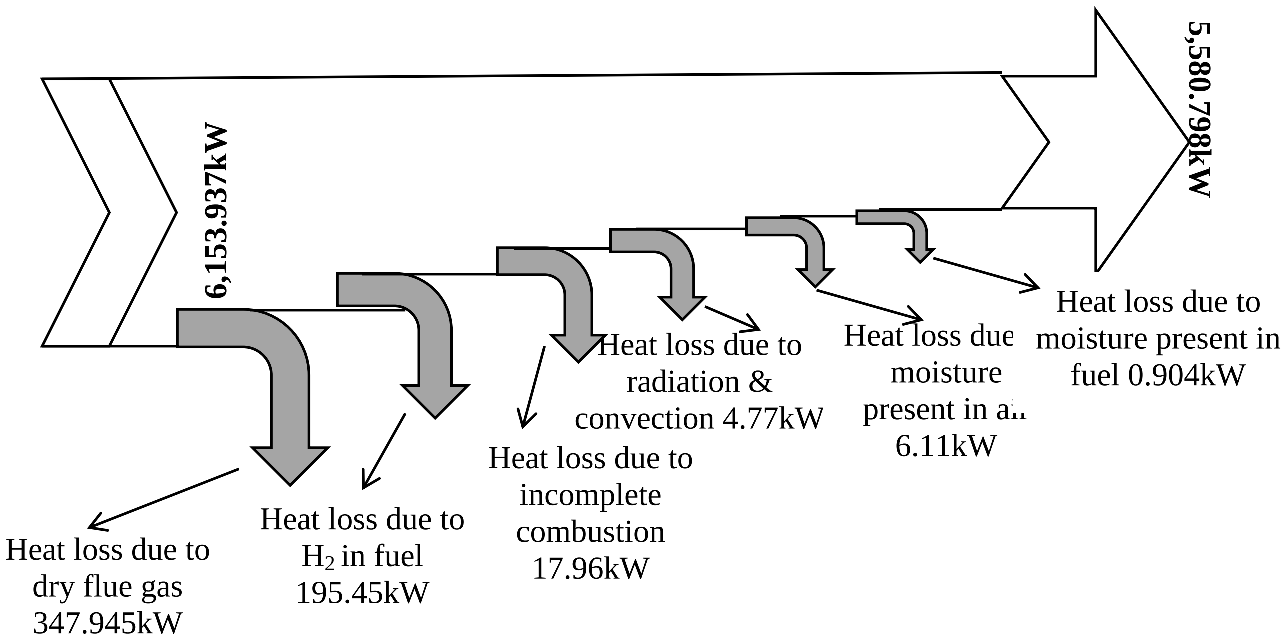


Figure 6.2 Sankey energy input and loss representation of boiler

6.3 Heat Balance on Three Glass Bottle Machine

The thermal energy analysis of the production process plant's bottle washer component indicated that 1,212,249.096 kWh of thermal energy were lost annually, and the thermal efficiency of the bottle washer had been determined to be 74.43%, 71.96%, and 68.166% of lines one, three, and five, respectively.

Saving power consumption is one of the goals of the thorough energy analysis and bad energy practices. Possible savings through various energy recovery techniques and energy-efficient technological strategies. The summary is shown in Figure 6.3.

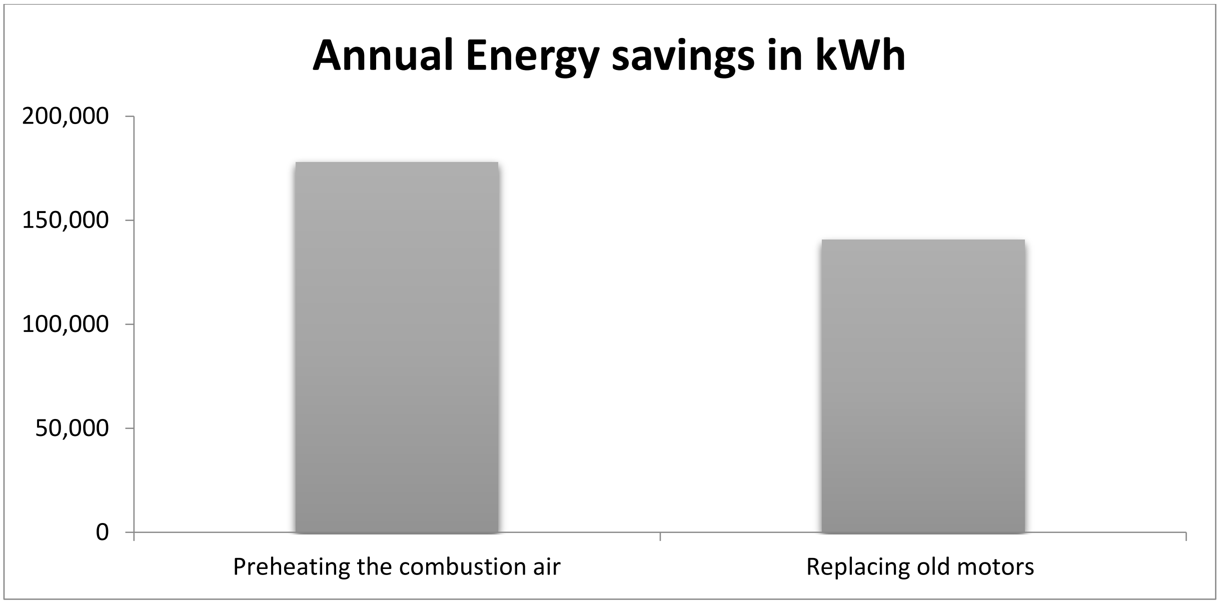


Figure 6.3 Factory potential annual energy savings

CHAPTER 7

ENERGY SAVING POTENTIAL IN THE FACTORY

7.1 Analysis of Possible Energy Savings Applying on Fire Tube Boiler.

Fire tube boilers are commonly used in industrial settings for heating water and generating steam. There are several ways to achieve energy savings in fire tube boilers, including the following:

- Improving Insulation: - Proper insulation of the boiler and piping can significantly reduce heat loss and improve energy efficiency. By minimizing heat loss, less energy is required to maintain the desired temperature, leading to energy savings
- Regular Maintenance: - Regular maintenance of the boiler, including cleaning the tubes, checking for leaks, and ensuring efficient combustion, can help optimize its performance and improve energy efficiency. A well-maintained boiler operates more efficiently, minimizing energy waste.
- Optimizing Combustion: - Ensuring proper combustion of fuel in the boiler can help improve energy efficiency. This includes ensuring the right air-to-fuel ratio, proper burner operation, and regular tuning of the combustion system.
- Installing Economizers: - Economizers are heat exchangers that recover heat from the flue gases exiting the boiler and use it to preheat the feedwater entering the boiler. By utilizing this waste heat, economizers can improve boiler efficiency and reduce fuel consumption.
- Implementing a Boiler Management System: - A boiler management system can optimize the operation of the boiler based on demand, load requirements, and other factors. By controlling the boiler more effectively, energy consumption can be reduced, leading to energy savings.
- Using Energy-Efficient Controls: - Installing energy-efficient controls, such as a modulating burner or a variable speed drive for pumps, can help optimize the energy usage of the boiler system. These controls can adjust the output of the boiler based on actual demand, improving efficiency.

- Monitoring and Benchmarking Performance: - Regularly monitoring the boiler's performance and comparing it to benchmarks can help identify areas for improvement and track energy savings. Data analysis can reveal trends and patterns that can be used to optimize the boiler operation further.

By implementing these strategies and technologies, significant energy savings can be achieved in fire tube boilers, leading to lower operational costs and reduced environmental impact. Regular maintenance, monitoring, and optimization are key to ensuring long-term energy efficiency and savings in boiler operations.

Preheating the Combustion Air

Preheating the combustion air is a process in which the intake air that is fed into a combustion chamber is heated before it is mixed with fuel and burned. This helps increase the efficiency of the combustion process by increasing the temperature of the air, which in turn enhances the combustion reaction and reduces energy losses.

Calculating Theoretical Heat Recovery Potential

The total heat transfer coefficient needs to be determined in order to compute the transferred heat from flue gas to combustion air.

Amount of heat transfer can be calculated either by using the air property or flue gas property and given by the below equation:

The cross flow over the pipe bundle that serves as the recuperator's external flow is calculated using thermophysical characteristics. The recuperator's pipes were arranged squarely and regularly. By taking into account the dew point temperature of dry exhaust flue gas and the goal of raising the temperature of combustion air, the temperature of flue gas was intended to drop from 241°C to 180°C with the use of a recuperator.

The below table gas represents the thermo physical properties of flue gas and ambient air

Table 7.1 Physical properties of flue gas and ambient air

Flue gas properties	$T_f$in	241^{O}C	combustion air properties	T_{air} in	23.5^{O}C
	Tf out	180^{O}C		Cp $_{air}$	1.009kJ/kg k
	cp_f	1.357kJ/kg K		k $_{air}$	0.03W/m k
	k_f	0.035W/m K		μ_{air} @ 23.5^{O}C	18.29*10^{-6}N.s/m^2
	μ_f	3.03*10^{-5}N.s/m^2		k stainless steel	50 W/m k

$$\begin{aligned} Q &= m_{air} * cp_{air} * (T_{air\ out} - T_{air\ in}) \\ &= m_f * cp_f * (T_{f\ out} - T_{f\ in}) \end{aligned} \tag{7.1}$$

By substituting the value from table 7.1 into equation 7.1 and calculated mass dry flue gas and air supplied from chapter five (m_f=18.67kg/kg and m_{air}=18.96kg/kg) to calculate the amount of heat transfer,

$$\begin{aligned} \dot{m}_f &= 18.67 kg/kg * 0.019 kg/s \\ &= 0.354 kg/s \\ \dot{m}_{air} &= AAS * \dot{m}_{fuel} \\ &= 18.96 kg/kg * 0.019 kg/s \\ &= 0.36 kg/s \end{aligned}$$

$$\begin{aligned} Q &= 0.354\text{kg/s}*1.357\text{kJ/kgk}*(241-180)^o C \\ &= 29.303 kW \end{aligned}$$

This study identified a 29.303 kW thermal energy recovery potential and constructed a cross flow recuperator with two passes for cold and one for hot. From equation 7.1 the outlet combustion air temperature can be calculated as below

$$T_{air\ out} = \frac{Q}{m_{air} * cp_{air}} + T_{air\ \text{in}} \tag{7.2}$$

$$\begin{aligned} T_{air\ out} &= \frac{29.303 kW}{0.36\, kg/s * 1.009\, kJ/kg\ \text{k}} + 23.5 \\ &= 104.17^O C \end{aligned}$$

A recuperator is a type of heat exchanger that is used to recover and reuse waste heat in various industrial processes. The primary function of a recuperator is to transfer heat from a hot stream to a colder stream, thereby improving the overall energy efficiency of the system.

Key features and functions of a recuperator:

- Heat recovery: Recuperators capture waste heat from high-temperature exhaust streams, such as those from furnaces, boilers, or turbines, and use it to preheat the incoming air or other process fluids.
- Improved efficiency: By preheating the incoming stream, the recuperator reduces the amount of energy required to bring the stream to the desired operating temperature, resulting in significant energy savings and improved overall system efficiency.
- Design: Recuperators are typically designed as a counter-flow or cross-flow heat exchanger, with the hot and cold streams flowing in opposite or perpendicular directions, respectively, to maximize heat transfer.
- Materials: Recuperators are often made from materials that can withstand high temperatures, such as stainless steel, alloy steel, or ceramic materials, depending on the specific application and operating conditions.
- Applications: Recuperators are used in a wide range of industries, including power generation, manufacturing, chemical processing, and metal processing, where efficient heat utilization is crucial for reducing energy consumption and operating costs.

By incorporating a recuperator into industrial processes, the overall energy efficiency can be significantly improved, leading to cost savings and reduced environmental impact through lower fuel consumption and emissions.

Logarithmic mean temperature difference is a critical parameter for determining the overall heat transfer coefficients, heat transfer rates, and optimizing the design of heat exchangers to achieve the desired thermal performance, and it’s determined as below

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})} \tag{7.3}$$

$$\Delta T_{lm} = \frac{(241-104.17)-(180-23.5)}{ln(\frac{136.83}{156.5})}$$
$$=146.4^{O}C$$

The convective heat transfer coefficient on the tube side in heat exchangers corresponds to the rate of heat transfer between the fluid flowing inside the tubes and the tube wall. This coefficient is a critical parameter in determining the overall heat transfer rate in the heat exchanger. The tube side convective heat transfer coefficient also calculated by using equation 8.4 by assuming Φ_i =1

Condensers and boilers typically require bigger tube diameters 20 mm for the purpose of in-tube cleaning (Kakac, 2012). The anticipated outer tube diameter of 3/4 inches with a Birmingham Wire Gage of 18 is chosen from Appendix E. Pitch ratio PT/do is often selected for tubes with a pitch ratio of 1.25 to 1.5 (Kakac, 2012).The outer and inner diameter and pitch to be 0.01905, 0.01656 and 0.0254 m respectively.

According to (Basheer et.al., 2018), the ratio of shell diameter to tube length should be between 1/5 and 1/15. The typical estimate for shell diameter is 150–1067 mm (Kakac, 2012). It is assumed for this design to be 1045 mm, with an 8-to-1 tube length to shell diameter ratio. Since the number of tubes is assumed to be 20, the tube length is computed by multiplying the ratio of tube length to shell diameter by the shell diameter, resulting in 10 tubes each pass.

$L = 8*$ diameter of the shell

=8*1.045m

=8.36m

Area of single tube

$$A = \pi * d_o * \text{L}$$
$$= \pi * 0.01905 * 8.36$$
$$= 0.5m^2$$

Cross sectional area of the inner tube can be calculated as below

$$A = \pi * \left(\frac{d_i}{2}\right)^2$$
$$= 0.0002153m^2$$

The total flow area of the tube multiplied by the total number of tubes each pass yields $0.002153m^2$, which is the total flow area.

Substituting the above data by assuming the Pr to be 0.71 and calculating the Reynolds number and convective heat transfer coefficient of tube side by using equation 7.4 and 7.5

$$\mathrm{Re} = \frac{\dot{m} * d_i}{A_t * \mu} \tag{7.4}$$

$$\mathrm{Re} = \frac{0.36 kg/s * 0.01656 m}{0.002153 m^2 * 18.29 * 10^{-6} N.s/m^2}$$
$$= 151,392.75 \text{ which is } > 3000 \text{ and it is turbulent flow}$$

$$h_i = \frac{k}{d_i} * 0023 * \mathrm{Re}^{0.8} * pr^{1/3} \tag{7.5}$$

$$h_i = \frac{0.03}{0.01656} * 0.023 * (151,392.75)^{0.8} * (0.71)^{1/3}$$
$$= 517.955 W/mk$$

Also, the shell side convective heat transfer coefficient and Reynolds number is calculated using the below equation:

$$D_e = \frac{4 * (P_T^{\,2} - \pi \left(\frac{d_o}{2}\right)^2}{\pi * d_o}$$
$$= \frac{4 * (0.0254 m)^2 - \pi \left(\frac{0.01905}{2}\right)^2}{\pi * 0.01905}$$
$$= 0.0241 m$$
$$C = P_T - d_o = 0.00635 m$$

The bundle diameter bundle diametrical clearance is calculated by using k1=0.056 and n=2.291 and assuming (Basheer et.al., 2018) and become,

$$D_b = d_o * \left(\frac{n_t}{k_1}\right)^{1/n_t}$$
$$= 0.01905 * \left(\frac{2.291}{0.156}\right)^{1/2.291}$$
$$= 0.1513 m$$

$$D_s = 0.012 + 0.1513$$
$$= 0.1633m$$

Also, the baffle spacing and area of the shell is calculating as below

$$B = \frac{D_s}{5}, = \frac{1.633}{5} = 0.3266m$$
$$A_s = \frac{D_s * C * B}{P_T} = 0.00134m^2$$

Substituting the value into equation 8.6 and 8.7 into calculate the shell side convective heat transfer coefficient and Reynolds number by using Pr = 0.12

$$\mathrm{Re} = \frac{D_e * \dot{m}}{\mu * A_s}$$

$$\mathrm{Re} = \frac{0.0241m * 0.354kg/s}{3.03*10^{-5} N.s/m^2 * 0.00134m^2}$$
$$= 210{,}122.65 \text{ which is > 3000, its turbulent flow}$$

$$h_o = \frac{k}{D_e} * 0.023 * \mathrm{Re}^{0.8} * \mathrm{Pr}^{1/3} \quad (7.6)$$

$$h_o = \frac{0.035}{0.024} * 0.023 * (210{,}122.65)^{0.8} * 0.12^{1/3}$$
$$= 297.69W/mk$$

The overall heat transfer coefficient can be determined by estimating the fouling factor for flue gas and combustion air to be 2000 and 5000 $W/m^{2}\ {}^{O}C$ respectively (Kakac, 2012) (Basheer et.al., 2018).

$$\frac{1}{U_o} = \frac{d_o}{h_i * d_i} + \frac{1}{R_a} + \frac{d_o ln(d_o/d_i)}{2k} + \frac{1}{R_f} + \frac{1}{h_o} \quad (7.7)$$

$$\frac{1}{U_o} = \frac{0.01905}{517.955*0.01656} + \frac{1}{5000} + \frac{0.01905*ln\left(0.01905/0.01656\right)}{2*50} + \frac{1}{2000} + \frac{1}{297.69}$$
$$= 0.0022 + 0.0002 + 0.00027 + 0.0005 + 0.0034$$
$$= 0.00657$$
$$U_O = 152.207 W / m^2 k$$

The heat transfer between two fluids refers to the process of thermal energy exchange between two fluids (liquids or gases) that are in thermal contact with each other. This heat transfer occurs due to a temperature difference between the two fluids, and the direction of heat flow is from the hotter fluid to the cooler fluid. By using heat transfer between two fluid formulas the required surface area is calculated using equation 7.8

$$\text{Q} = F_T * U_o * A \Delta T_{lm} \tag{7.8}$$

$$P = \frac{T_{c2} - T_{c1}}{T_{h2} - T_{c1}} = \frac{104.17 - 23.5}{241 - 23.5} = 0.371$$

$$R = \frac{T_{h2} - T_{h1}}{T_{c2} - T_{c1}} = \frac{241 - 180}{104.17 - 23.5} = 0.756$$

$$\alpha = \left[\frac{1 - RP}{1 - P}\right]^{1/N_{shell}} = \left[\frac{1 - 0.371*0.756}{1 - 0.371}\right]^{1/1} = 1.144$$

$$\text{S} = \frac{\alpha - 1}{\alpha - R} = \frac{1.144 - 1}{1.144 - 0.756} = 0.371$$

$$F_T = \frac{\sqrt{R^2 + 1} ln\left(\frac{1 - S}{1 - R*S}\right)}{(R-1) ln\left(\frac{2 - S\left(R + 1 - \sqrt{R^2 + 1}\right)}{2 - S\left(R + 1 + \sqrt{R^2 + 1}\right)}\right)} = \frac{\sqrt{0.756^2 + 1} * ln\left(\frac{1 - 0.371}{1 - 0.756*0.371}\right)}{(0.756 - 1) ln\left(\frac{2 - 0.371*\left(0.756 + 1 - \sqrt{0.756^2 + 1}\right)}{2 - 0.371*\left(0.756 + 1 + \sqrt{0.756^2 + 1}\right)}\right)} = 0.9623$$

The surface area become

$$A = \frac{\text{Q}}{F_T * U_o * \Delta T_{lm}} = \frac{29.303}{0.9623*152.207*146.4} = 1.367 m^2$$

By using a recuperator and a cross flow heat exchanger, the combustion air will be heated from 23.5 °C to 104.17 °C and the flue gas will be cooled from 241 °C to 180 °C, with the combustion air remaining unmixed and the flue gas mixed.

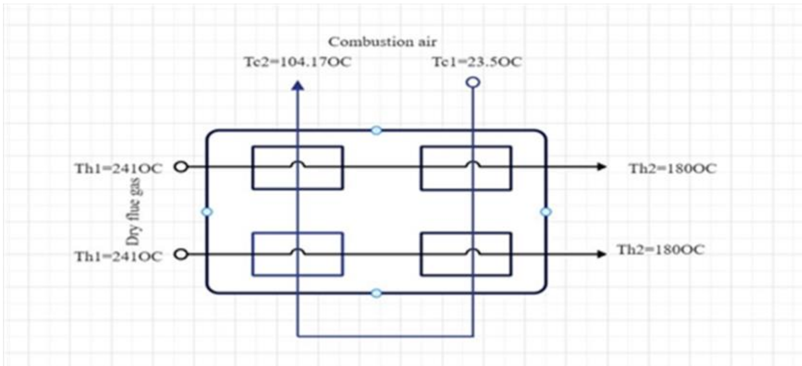


Figure 7.1 Designed cross flow heat exchanger

A 20°C rise in combustion air temperature provides a 1% increase in boiler efficiency. The yearly energy saving is going to be:

$$\begin{aligned}\text{Annual Energy Saving} &= \dot{m}_f * GCV * (\eta_{new} - \eta_{old}) \\ &= 0.0635 * 46.05 * (88.84\% - 84.81\%) * 365 * 24 * 3600 \\ &= 3{,}716.33 GJ / year\end{aligned}$$

The cost of using a recuperative heat exchanger to pre-heat combustion air with a temperature range of 10–200℃ is determined to be: the purchasing price 250,000 ETB (Kelvion), freight and handling 100,000 ETB, installation 50,000 ETB, opportunity cost 40,000 ETB and the total initial investment cost become 440,000 ETB.

An Evaluation of the System's Costs and Benefits

The 3,716.33 GJ of energy saved annually indicates that around 86,426.28 kilograms of fuel can be saved annually. This leads to a fuel savings of 102,144 liters at an anticipated cost savings of 8,145,984 ETB with current diesel value of 79.75 ETB/Litter.

Cash Flow

The heat exchanger is expected to work properly more than 10 years and the fuel cost will be estimated to increase with average price of 25% within each year, and summarized by the below table.

Table 7.2 Cash flow for the recuperator

Working year	Expenditure (ETB)	Litter	Expected Diesel value per litter (ETB)	Profit (ETB)
1	440,000	102,144	79.75	8,145,984
2	12,000	102,144	99.69	10,182,735
3	12,000	102,144	124.61	12,728,164
4	12,000	102,144	155.76	15,909,949
5	12,000	102,144	194.70	19,887,437
6	12,000	102,144	243.38	24,859,807
7	12,000	102,144	304.22	31,074,248
8	12,000	102,144	380.28	38,843,320
9	12,000	102,144	475.38	48,557,215
10	12,000	102,144	594.18	60,691,922
salvage value with depreciation rate of 10%			-	435,619.75

Present Value Analysis

Consider a 17% interest rate, which is comparable to the commercial bank of Ethiopia's lending rates. The equation for calculating the present worth of future money is:

$$PV_i = \frac{FV_i}{(1+r)^{n_i}} \tag{7.9}$$

where,

PV - is Present value

FV - Future of the cash flow

r - rate or interest rate

n - Number periods until the cash flow is received

Table 8.7.3 Present value result of the heat exchanger for 10 years

Working year	interest rate	cash flow	PV
1	17%	8,145,984	6,962,379.49
2		10,182,735	7,438,626.17
3		12,728,164	7,947,090.74
4		15,909,949	8,490,345.29
5		19,887,437	9,070,881.72
6		24,859,807	9,691,312.04
7		31,074,248	10,353,795.69
8		38,843,320	11,061,892.97
9		48,557,215	11,819,007.59
10		60,691,922	12,626,188.62
Total			95,461,520.31

The payback period is a capital budgeting metric that measures the time it takes for the net cash inflows from an investment to equal the initial cash outlay. In other words, it's the amount of time it takes to recoup the original investment.

The payback period is calculated as follows:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Cash Inflow}} = \frac{440,000}{8,145,984} = 0.054 \text{ year } \approx 20 \text{ days}$$

7.2 Analysis of Electrical Motors and Machine Drives for Possible Reductions in Energy Consumption

By considering the below factors, it can identify and implement strategies to reduce the energy consumption of electrical motors and machine drives, leading to cost savings and environmental benefits.

- Motor efficiency: Evaluate the efficiency of the existing motors and identify opportunities to replace older, less efficient models with high-efficiency motors. Consider the use of premium efficiency (IE3) or super-premium efficiency (IE4) motors, which can offer significant energy savings compared to standard efficiency motors.

- Variable-speed drives (VSDs) or variable-frequency drives (VFDs): Assess the potential for implementing VSDs or VFDs on motor-driven systems, such as fans, pumps, and compressors, where the load varies. VSDs/VFDs can provide significant energy savings by allowing the motor speed to be adjusted to match the actual load requirements, rather than running the motor at a constant speed.
- Proper motor sizing: Ensure that motors are sized appropriately for the application, avoiding oversizing, which can lead to lower efficiency and higher energy consumption. Optimize the motor and drive system to match the actual load requirements, which can result in energy savings.
- Maintenance and repair: Maintain motors and drives regularly to ensure optimal performance and efficiency. Address issues such as bearing wear, imbalance, misalignment, and other mechanical problems that can reduce efficiency and increase energy consumption.
- Load matching: Evaluate the load profile of the motor-driven systems and identify opportunities to match the motor output to the actual load requirements. This can involve implementing control strategies, such as load-sensing controls or multi-speed motors, to better match the motor output to the load.
- System-level optimization: Consider the entire system, including the motor, drive, and driven equipment, when analyzing energy-saving opportunities. Optimize the system-level efficiency by considering factors such as pipe or duct sizing, system configurations, and control strategies.

Replacing ordinary electrical motors with energy-efficient ones

Motor that uses less energy minimize energy losses by using better materials, tighter tolerances, better design, and enhanced production processes. Energy-efficient motors can also stay colder, potentially aid lower facility heating loads, it have greater service factors, longer insulation lives, longer bearing lives, and less vibration when installed properly.

The following formula might be used to determine the annual energy savings from switching from a regular motor to an energy-efficient motor (Hasanuzzaman, 2010):

$$AES = h_p * L * 0.746 * h_r * N_m \left[\frac{1}{E_{nm}} - \frac{1}{E_{ee}} \right] * 100 \qquad (7.10)$$

Where, AES = Expected annual bill savings

hp = Motor rated horsepower

L = Load factor (percentage of full load)

0.746 = Conversion factor from horsepower to kW

hr = Annual operating hours

E_{nm} = Normal motor efficiency (%)

E_{ee} = Energy-efficient motor efficiency rating (%)

Calculating the yearly bill savings linked to the energy savings mentioned above may be done as follows:

$$\text{Savings} = AES * c \quad \text{, c=Average energy cost} \qquad (7.11)$$

Calculating the yearly bill savings linked to the energy savings mentioned above may be done as follows:

Table 7.4 Utilizing highly efficient motors present an annual chance to save electrical energy.

Pr[kW]	E_{nm}	E_{ee}	AES [kWh]
0.75	73	78	20,408.50
1.5	73	79	6,058.60
2.2	73	80	2,458.60
3	73	79	49,854.50
4.5	77	84	12,589.70
6.4	73	83	4,856.90
7.5	73	81	6,258.89
11	73	80	16,584.12
12	73	83	6,879.20
15	89	85	14,587.90
Total			140,536.91

The saving amount is calculated by substituting current energy cost of 2.61ETB/ kWh in question 7.11

Savings= 140,536.91*2.61=366,801.335 ETB

The purchase price of 105 high-efficiency motors is approximated based on their rated capacity will be 450,000 ETB, Hence the payback period is calculated as below

$$\text{Payback period} = \frac{\text{Investment cost}}{\text{saving}}$$

$$= \frac{450,000}{366,801.335}$$

$$= 1.2268 \text{ Year} \approx 448 \text{ Days}$$

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

To ensure sustainable industrial development in both developed and developing nations, manufacturing industries must embrace energy-saving opportunities. This study identifies potential energy-saving strategies and examines the energy consumption performance of the East Africa Bottling Share Company. According to research, the fuel's electrical and thermal energy are the factory's main sources of energy. The power rating and operating hours of energy-consuming machinery and equipment are noted during an overview energy audit.

The actual measurement values of current, power factor, flue gas characteristics and flows, boiler surface temperature, hot water temperature, and various laboratory measurements are all measured using different instruments in this study. When direct measurement is challenging, reading boards are used to collect data.

Boilers are used to generate steam in industries, For Coca Cola company the steam is used to wash bottles in RGB lines (to dissolve caustic soda), to dissolve sugar and for CIP purpose. The calculated percentage of the steam boiler is become 84.81%. In this study the efficiency of the boiler can be increased by using the heat which is exhaust in dry flue gas to heat combustion air. The company has 105 electric motor drives, among them this study found old motors with low efficiency and estimated annual losses occurred.

8.2 Recommendations

To enhance energy efficiency at the East Africa Bottling share company, make use of the following recommendations.

- Replacing large and outdated motors in the production process
- The factory must implement energy-saving measures, address indicated steam leaks and surfaces, and undertake regular inspections.
- Controlling waste heat sources can increase the boiler's efficiency.
- A responsible group should manage, monitor, and report on the company's utilization of energy.

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Appendix A: The fuel properties and flue gas measured values

Ambient temperature ^{O}C	Flue Gas Analysis			
	O_2%	CO%	CO_2%	Temp of Flue gas ^{O}C
23.5	5.2	0.032	11.8	241

Property		Diesel
Specific gravity @15°C		0.8329
Flash point		65.5
Ash %		0.01
Moisture content %		0.05
Calorific value (MJ/kg)		46.05
Elemental analysis %	C	81
	H	14
	N	1.97
	O	0.38
	S	0.61

Appendix B: the fire tube boiler dimensions and measured Temperature

Parameters	Measured temperature	
Diameter = 1.6m		
Length = 3.36m	Front surface	95^{o}C
Ambient temperature = 23.5℃	Bottom surface	70^{o}C
Wind velocity = 2.5m/s	Cylindrical Surface	66^{o}C

Appendix C: Rated power and current of electrical motors of plant

Location of Motor	Collected Data of Rated Power(kW)	Collected Data of Rated Eff.	Measured input Elec. power	Calculated Motor Loading (%)	Service year
Air Compressor	90	73	68	75.6	6
	37	73	32	86.5	6
Boiler,	4	73	2.5	62.5	8
	12	73	3.4	28.3	8
	3	73	1.2	40	8
Bore Hole 1	30	89	21.5	71.7	9
	15	89	11.3	75.3	8
Filler	5.5	73	3.72	67.6	7
	1.75	73	0.45	35.6	7
	1.5	73	0.5	33.3	7
	0.75	73	0.41	54.7	7
Filler-Labeler	1.1	77	0.23	20.9	7
	1.1	77	0.53	48.2	8
	1.1	77	0.52	47.3	8
	1.1	77	0.47	42.7	7
	1.1	77	0.5	45.5	7
	1.1	77	0.52	47.3	7
	1.1	77	0.54	49.1	7
	1.1	77	0.5	45.5	7
	1.1	77	0.52	47.3	7
	1.1	77	0.49	44.5	7
	1.1	77	0.48	43.6	7
	1.1	77	0.52	47.3	7
	1.1	77	0.49	44.5	7
	1.1	77	0.55	50	7
Labeler	6.4	73	5.4	84.4	7
	1.5	73	1.08	72	7
Labeler-Packer	1.5	77	0.53	35.3	7
	1.1	77	0.52	47.3	7
	1.1	77	0.53	48.2	7
	1.1	77	0.5	45.5	7
	1.5	79	0.48	32	7
Loader-Unpacker	0.75	73	0.28	37.3	13
	0.75	73	0.26	34.7	13
Packer	3	73	2.52	84	7
	1.5	73	1.18	78.7	7
	1.5	73	1.15	76.7	7
	1.5	73	1.2	80	7

	0.75	73	0.54	72	7
Packer-Unloader	0.75	73	0.36	48	8
	0.75	73	0.36	48	8
	0.75	73	0.41	54.7	8
	0.75	73	0.44	58.7	6
	0.75	73	0.4	53.3	6
	0.75	73	0.4	53.3	6
	0.75	73	0.42	56	6
	0.75	73	0.38	50.7	6
	0.75	73	0.36	48	8
	0.75	73	0.41	54.7	8
Unpacker	3	73	2.64	88	7
	1.5	73	0.54	36	8
	1.5	73	0.53	35.3	8
Unpacker-Bottle Washer	1.1	77	0.58	52.7	6
	1.1	77	0.48	43.6	7
	1.1	77	0.55	50	6
	1.5	77	0.47	31.3	9
	1.5	77	0.56	37.3	9
Washer	5.5	73	3.34	60.7	6
	5.5	73	3.44	62.5	6
	7.5	73	5.16	68.8	6
	4.5	77	2.8	62.2	6
	4	77	3.26	81.5	6
	4	77	2.75	68.8	6
	4	77	2.88	72	6
	4	77	2.9	72.5	6
	0.75	77	0.4	53.3	6
	0.75	73	0.41	54.7	6
	2.2	73	1.2	54.5	6
	1.5	79	0.62	41.3	7
	4	73	2.81	70.3	6
	7.5	77	5.33	71.1	6
	7.5	77	5.39	71.9	6
	1	73	0.41	41	6
	1	73	0.4	40	6
	1	73	0.44	44	6
	1	73	0.38	38	8
	1	73	0.36	36	8
	1.6	73	0.56	35	8
	5.5	73	3.84	69.8	6
	11	73	6.7	60.9	6

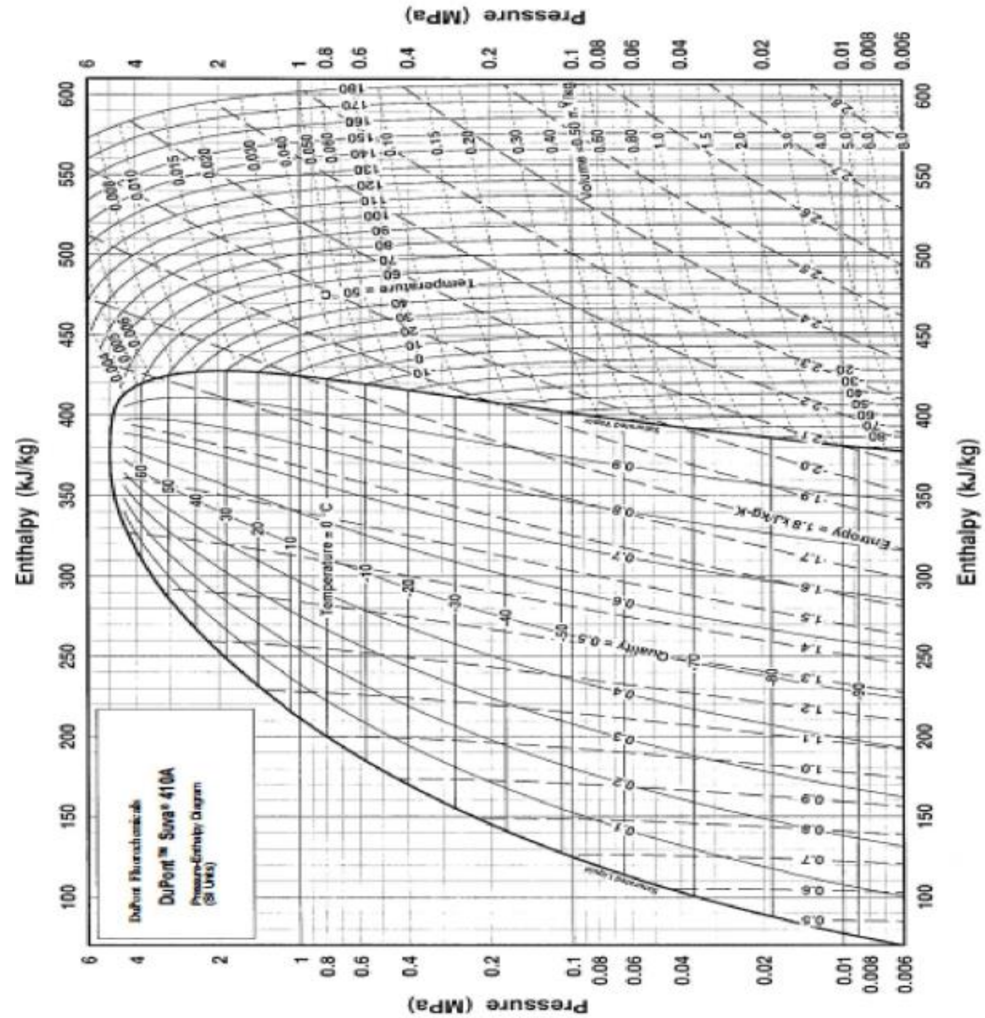
Washer-Filler	1.5	79	0.41	27.3	8
	1.5	79	0.36	24	8
	1.5	79	0.44	29.3	8
	1.5	79	0.48	32	13
	1.5	79	0.52	34.7	8
	1.5	79	0.58	38.7	8
	1.5	79	0.52	34.7	8
	1.5	79	0.48	32	8
	1.5	79	0.5	33.3	8
	1.1	77	0.48	43.6	8
	1.1	77	0.52	47.3	8
	1.1	77	0.55	50	8
	1.1	77	0.53	48.2	8
	1.1	77	0.5	45.5	8
	1.1	77	0.49	44.5	8
	1.1	77	0.48	43.6	8
	1.1	77	0.53	48.2	8
	1.1	77	0.48	43.6	8
	1.1	77	0.48	43.6	8
Water Treatment	11	91	7.54	68.5	8
	11	90	7.2	65.5	9
	15	91	11.6	77.3	7
	5.5	73	3.92	71.3	7
	5.5	73	4.08	74.2	7
	11	91	8.5	77.3	8
	1.5	73	0.9	60	7

Appendix D: Dimensional data for commercial tubing

Dimensional Data for Commercial Tubing

OD of Tubing (in.)	BWG Gauge	Thickness (in.)	Internal Flow Area (in.²)	Sq. Ft. External Surface per Ft. Length	Sq. Ft. Internal Surface per Ft. Length	Weight per Ft. Length, Steel (lb.)	ID Tubing (in.)	OD/ ID
1/4	22	0.028	0.0295	0.0655	0.0508	0.066	0.194	1.289
1/4	24	0.022	0.0333	0.0655	0.0539	0.054	0.206	1.214
1/4	26	0.018	0.0360	0.0655	0.0560	0.045	0.214	1.168
3/8	18	0.049	0.0603	0.0982	0.0725	0.171	0.277	1.354
3/8	20	0.035	0.0731	0.0982	0.0798	0.127	0.305	1.233
3/8	22	0.028	0.0799	0.0982	0.0835	0.104	0.319	1.176
3/8	24	0.022	0.0860	0.0982	0.0867	0.083	0.331	1.133
1/2	16	0.065	0.1075	0.1309	0.0969	0.302	0.370	1.351
1/2	18	0.049	0.1269	0.1309	0.1052	0.236	0.402	1.244
1/2	20	0.035	0.1452	0.1309	0.1126	0.174	0.430	1.163
1/2	22	0.028	0.1548	0.1309	0.1162	0.141	0.444	1.126
5/8	12	0.109	0.1301	0.1636	0.1066	0.602	0.407	1.536
5/8	13	0.095	0.1486	0.1636	0.1139	0.537	0.435	1.437
5/8	14	0.083	0.1655	0.1636	0.1202	0.479	0.459	1.362
5/8	15	0.072	0.1817	0.1636	0.1259	0.425	0.481	1.299
5/8	16	0.065	0.1924	0.1636	0.1296	0.388	0.49s	1.263
5/8	17	0.058	0.2035	0.1636	0.1333	0.350	0.509	1.228
5/8	18	0.049	0.2181	0.1636	0.1380	0.303	0.527	1.186
5/8	19	0.042	0.2298	0.1636	0.1416	0.262	0.541	1.155
5/8	20	0.035	0.2419	0.1636	0.1453	0.221	0.555	1.136
3/4	10	0.134	0.1825	0.1963	0.1262	0.884	0.482	1.556
3/4	11	0.120	0.2043	0.1963	0.1335	0.809	0.510	1.471
3/4	12	0.109	0.2223	0.1963	0.1393	0.748	0.532	1.410
3/4	13	0.095	0.2463	0.1963	0.1466	0.666	0.560	1.339
3/4	14	0.083	0.2679	0.1963	0.1529	0.592	0.584	1.284
3/4	15	0.072	0.2884	0.1963	0.1587	0.520	0.606	1.238
3/4	16	0.065	0.3019	0.1963	0.1623	0.476	0.620	1.210
3/4	17	0.058	0.3157	0.1963	0.1660	0.428	0.634	1.183
3/4	18	0.049	0.3339	0.1963	0.1707	0.367	0.652	1.150
3/4	20	0.035	0.3632	0.1963	0.1780	0.269	0.680	1.103
7/8	10	0.134	0.2892	0.2291	0.1589	1.061	0.607	1.441
7/8	11	0.120	0.3166	0.2291	0.1662	0.969	0.635	1.378
7/8	12	0.109	0.3390	0.2291	0.1720	0.891	0.657	1.332
7/8	13	0.095	0.3685	0.2291	0.1793	0.792	0.685	1.277
7/8	14	0.083	0.3948	0.2291	0.1856	0.704	0.709	1.234
7/8	16	0.065	0.4359	0.2291	0.1950	0.561	0.745	1.174
7/8	18	0.049	0.4742	0.2291	0.2034	0.432	0.777	1.126

Appendix E: Refrigerant R-410A Property



Appendix F: Refrigerant R-407C Property