Investigation of the Energy Performance of Pasta and Macaroni Factory - A Case of Africa P.L.C

M.Sc. Thesis

By

Degaga Abdi Busha

Thermal and Aerospace Engineering Program

School of Mechanical, Chemical and Materials Engineering

Adama Science and Technology University

Adama, Ethiopia

October, 2019

Approval of Board of Examiners

We, the undersigned, members of the board of examiners of the final open defense by Degaga Abdi have read and evaluated his thesis entitled "**Investigation of the Energy Performance of pasta and macaroni factory – A Case of Africa P.L.C"** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Masters of Science in thermal Engineering.

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Chairman, Department	Signature	Date
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Internal Examiner	Signature	Date
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External Examiner	Signature	Date

Investigation of the Energy Performance of

Pasta and Macaroni Factory - A Case of Africa P.L.C

A Thesis Submitted to Thermal and Aerospace Engineering Program of School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University in partial fulfillment of the requirements for the award of the degree of **Masters of Science in Thermal Engineering**

By

Degaga Abdi Busha

Advisor: Dr. Addisu Bekele

Adama, Ethiopia

October, 2019

Candidate's declaration

I hereby declare that the work which is being presented in the thesis entitled "**Investigation of the energy performance of pasta and macaroni factory – A Case of Africa P.L.C"** in partial fulfillment of the requirements for the award of the degree of Master of Science in Thermal Engineering is an authentic record of my own work carried out from October 2018 to September 2019 under the supervision of Dr. Addisu Bekele.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Name of Student

Degaga Abdi ---------------------- ----------------

Signature Date

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name of Advisor

Dr. Addisu Bekele ------------------------- -----------------

Signature Date

Acknowledgement

The greatest thanks go to the Creator of the Universe. I would like to thank him for giving me the opportunity, strengths and blessing in completing this thesis. Then, I would like to thank my advisor Dr. Addisu Bekele for his invaluable advice, inspiration and perseverance throughout this study.

I would also like to express my love and gratitude to my beloved wife; Talile Getaneh for her understanding and endless love.

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Executive summary

The increased use of energy has raised serious concern about the energy charges and demand. The objective of this study is to investigate energy performance analysis of Pasta and Macaroni factory for a case of Africa P.L.C through energy analysis. The detailed energy analysis is carried out by assessing the performance of energy consuming equipment. This thesis presents analysis of energy utilization and energy saving opportunities in the factory. The study is based on the realization that enormous potential exists for energy saving improvements in the existing energy consuming industrial equipment.

Up on the actual measured data, the two hot water boiler performance assessment is carried out by considering different heat losses. The typical boiler efficiency is of 81% and 80% for boiler-1 and boiler-2. The remaining part of the energy is lost in different forms of wasted heat. As per the analysis, the major heat loss is occurred due to dry exhaust flue gas. Additionally, water chiller, air compressor, driving electrical motors, pumps and lighting system equipments energy utilization and annual saving opportunities are determined in this study.

In pasta and macaroni production process the dryer section of the production process consumes huge amount of thermal energy to evaporate unnecessary moisture from the surface as well as the inner part of the product. This study investigate that about 6,885TJ/year, 9,539.6TJ/year and 10,132.5TJ/year energy is consumed annually by dryer-2, dryer-3 and dryer-4 respectively. After detailed analysis, the thermal efficiencies of typical dryers are to be observed 75.3%, 80% and 73.1% for dryer-2, dryer-3 and dryer-4 respectively. In general, after detailed thermal energy consumption was conducted, 26%, 36% and 38% of total annual thermal energy of 7,376,971 kWh was consumed by plant-2, plant-3 and plant-4 respectively.

It is also observed from the analysis that the driving motors of plant-2, plant-3 and plant-4 are consuming about 20%, 25% and 8% of the total 20,480,377kWh annual electrical energy consumed by the industry respectively and about 47% of the total electrical energy is consumed by the pump motor, air compressor, and chiller and lighting systems in the factory.

The investigation has revealed that the industry has significant energy saving potential. Different energy saving measures are adopted and it is found that the industry can save 262,681.4kWh per annum from using high efficient motors rather than normal motors, 782.6 GJ/year heat energy recovered from dry exhaust flue gas to preheat combustion air and 1221 GJ/year from excess combustion air controlling by using oxygen analyzer. This implies the total annual bill saving potential of the factory will be about 1,676,872 ETB per year.

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Symbols and Acronyms

RA	Theoretical air required [kg of air/kg of fuel]
AAS	Actual mass of air supplied per kg of fuel
C_p	Specific heat [kJ/kg]
T_f	Flue gas temperature [℃]
T_a	Ambient temperature [℃]
M	mass of moisture in fuel in 1 kg basis [%]
$\dot{m}_{f\ in}$	Mass flow rate of flour [kg/hr]
H_{in}	Inlet moisture [kg/kg of pasta]
H_{out}	Outlet moisture [kg/kg of pasta]
E	Evaporated moisture [kg]
Q_{in}	Heat input [kW]
I_m	Measured current [A]
P_{in}	Power input [kWh]
L	Electrical loading [%]
η	Efficiency [%]
AEC	Annual Energy consumption [kWh]
AES	Annual energy saving [kWh]
ATEC	Annual thermal energy consumption [kWh]
V_m	Measured voltage [V]
V_r	Rated voltage [v]
AEL	Annual energy loss [kWh]
P.f	Power factor [%]
P_{UL}	Power during unloading [kW]
P_L	Power during loading [kW]
SME	Specific mechanical energy [kJ]
$E_{e,dm}$	Electrical energy consumed by driving motor [kWh]
E_e	Electrical energy consumed [kWh]
EEM	Energy efficient motor [kWh]

CHAPTER 1
Introduction

1.1. Background of the study

Industries are the major contributors for the economic development of any country. In many of the African countries including Ethiopia, industries are vast in numbers in which most of the energy requirements are met through electrical energy followed by the thermal energy. Industry sector has been consuming a lot of energy for their various processes during the production. The energy efficiency and conservation have become one of the key factors to address energy utilization problem.

The increased use of energy has raised serious concern about the energy charges and demand. It has to be overcome through the improved end use energy efficiency. A detailed energy performance study is conducted on Pasta and Macaroni factory for a case of Africa PLC to identify the energy saving potential.

As it is known energy conservation is the appropriate utilization of the limited energy source. Investigation of energy performance through energy analysis is the general term for a systematic procedure that aims at obtaining an adequate knowledge of the energy consumption profile of the Pasta and Macaroni factory for a case of Africa P.L.C. It also aims at identifying and scaling the cost-effective energy saving opportunities for the unit. Energy analysis is a crucial in the implementation of energy saving measures and in the assurance of the targets of energy management.

This study investigates the energy performance of the equipments by adopting the energy conservation measures. Energy analyses are applied focusing on the boiler, electrical motors, lighting system and air compressor, to spot the energy use pattern, energy saving potential, emission saving capability and bill savings. The investigation identifies the industry energy saving and bill saving potential.

Energy analysis is the key to a systematic approach for decision making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. The aim of this study is to investigate the energy performance of Africa PLC (Pasta and Macaroni) thorough detailed energy analysis. It is necessary to measure and evaluate a set of parameters that are used to investigate the energy performance of the factory:

i. End use energy input to the unit, i.e. electricity and heat energy.
ii. Energy flow, conversion and losses, in distinguished production and building facilities, like flows and losses of hot water, electricity and thermal energy.
iii. Flows of raw materials, intermediate and final products, when these are directly related to energy flows. Measurements of the products' weight, numbers of units manufactured and of the composition of the materials used, are included here.

1.2. Statement of the problem

With rapidly increasing energy demand and charges, pasta and macaroni manufacturers seek opportunities to reduce production costs. Investment in energy efficient technologies can make a significant contribution towards reducing production costs. So, it is important to keep records of how much energy the Pasta and Macaroni factory for a case of Africa P.L.C is using and their costs as well as the energy performance of the equipment. An energy analysis coupled with good records can help to identify opportunities to change current practice or identify areas where simple changes, upgrades, timings or investment can help to improve business performance.

The research questions and sub questions that are to be addressed in the study are;

i. How appropriately is this factory utilizing energy?
ii. How is the total energy distributed in the factory?
iii. How is the factory performing?
iv. Which system consumes more energy?
v. What feasible energy management opportunities are available in the factory?
vi. What is the amount of energy utilized per unit of production in the factory?
vii. What is the overall efficiency of the factory systems?

1.3. Objectives

This thesis focuses on the energy analysis of Pasta and Macaroni Factory for a case of Africa P.L.C which is located in Adama town. The factory faces different challenges due to lack of appropriate utilization of energy that causes inefficient energy consuming facilities.

1.3.1. General objective

The general objective of this thesis is to investigate and analyse the way energy is being utilized in Pasta and Macaroni Factory for a case of Africa P.L.C and identify energy saving potential to reduce energy costs after implementation.

1.3.2. Specific objectives

In order to achieve general objective, the following specific objectives represent the core of this mission.

- Review the energy management system of the factory
- Conduct detail energy analysis of the factory
- Identify potential energy saving areas
- Recommend energy saving opportunities
- Perform the cost and benefit analysis of implementing the identified energy saving opportunities

1.4. Materials and methodology

The energy audit was conducted at Pasta and Macaroni Factory for a case of Africa P.L.C, Adama, Oromia states of Ethiopia. It has many types of equipment and heavy machinery like hot water boiler, air compressor, water chiller and processing machine. The Company's primary source of power supply is fuel oil and 3 giant electric transformers. Portable test equipment like the flow meter, thermocouple, and digital tachometer, power analyzer and multi-meter were used in determining flow rates, temperature and electrical readings.

In preliminary data collection phase, exhaustive data collection was made using different methods such as observation, and measurements. It is done by visiting the working machines, laboratories, offices and other entities of the company. Information about the general electrical appliances was collected by observation and interviewing. The electricity bill was collected from the personnel in-charge. The power consumption of appliances was measured using power analyzer. In many processes the extent of power consumption would be variable and depend on process stage and time elapsed after pasta was introduced for drying, in such cases many instant readings were taken by portable instrument. Electrical motors from input to output products data collected for three different production plant lines with their rated and through measurement.

To measure power consumption, current consumption, load factor and power factor by different electrically driven system clamp on power meter is used. The clamp-on feature of the meter enables to record the measurements without disrupting normal operation. Thermocouple sensors are used to measure boiler surface temperature.

During preliminary audit, interview with key facility personnel was conducted in order to find scope of work, facility rules and regulation, roles and responsibilities of team members and description of scheduled project activities. The major energy consumption areas were identified during facility tour. Availability of various documents related to major consumption was reviewed. The methodology used during conducting this thesis is summarized in the Figure 1.1 below.

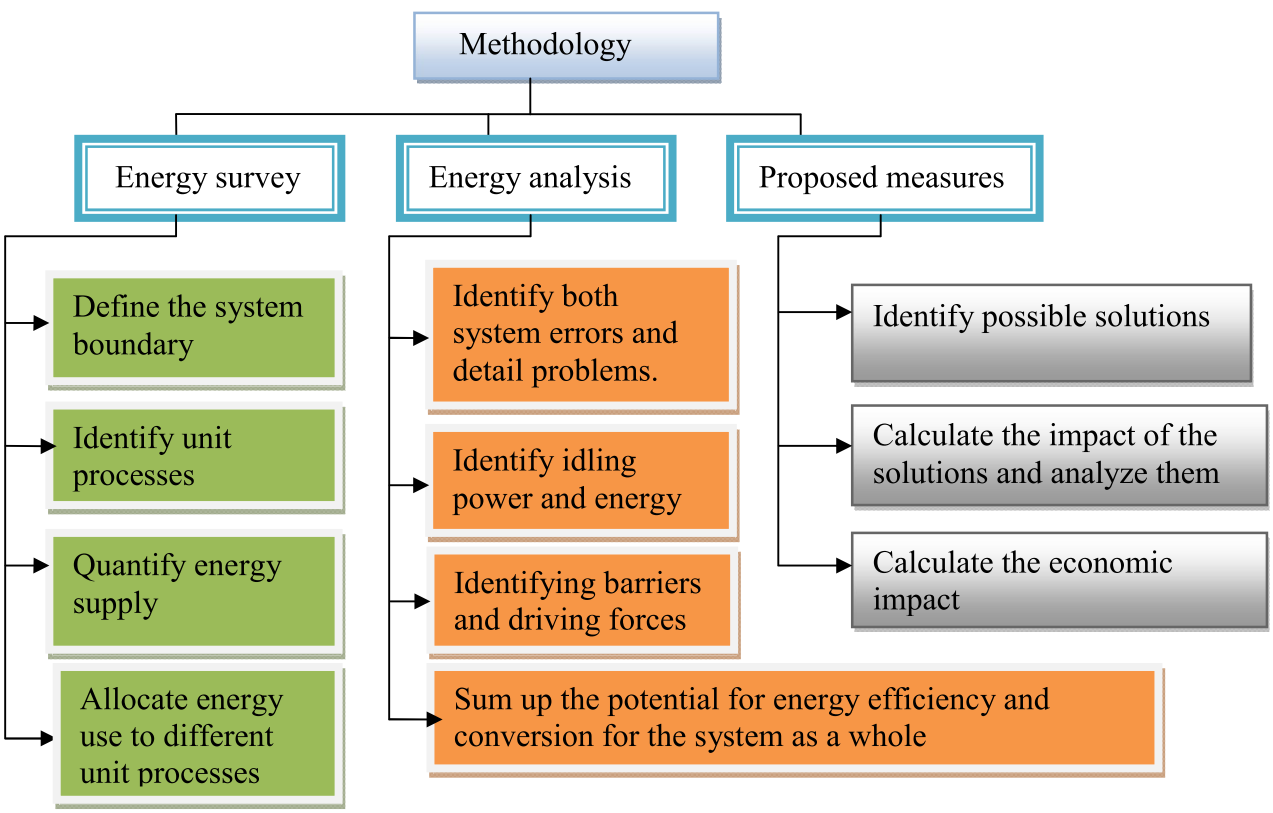


Figure 1.1.Methodology

1.5. Scope of the study

The scope of study is the thermal and electrical energy analysis and the total energy utilization of the pasta and macaroni factory for a case of Africa P.L.C was conducted. Based on the actual measured data, the fire tube boiler and plants dryers' performance assessment is carried out. Additionally, water chiller, air compressor, driving electrical motors, pumps and lighting system equipments energy utilization and annual saving opportunities was determined in this study.

1.6. Significance of the study

This study helps the factory to understand and analyze its energy utilization and identify areas where energy use can be reduced, decide on how to budget energy use, plan and practice feasible energy conservation methods that will enhance their energy efficiency, curtail energy wastage and substantially reduce energy costs. The energy audit serves to identify all the energy streams in a facility, qualify energy usage with its discrete functions, in an attempt to balance the total energy input with its use

Therefore outputs of this thesis could be very important for the future similar industries to mitigate the challenges of energy consumption. In order to conserve the energy there has to be the necessary knowledge as to how it is being wasted. This can only be obtained through performing an investigation on energy utilization. The proper energy utilization is going to be achieved through continual assessment of the energy utility in an industry. This in turn will reduce the unnecessary loss of energy to the environment.

CHAPTER 2

Literature Reviews

2.1. Introduction

The literature survey is made to realize and provide the relevant information on the thermal energy, electricity consumption, energy efficiency and energy related emission from the various industries by focusing on the following:

- Energy analysis on various energy intensive equipment
- Energy saving potential in the industry

According to the statistical review of the world Energy Information Administration (EIA), percentage of the world energy consumption by various sectors is shown in Figure 2.1. It is clear that the industrial sector consumes more than half of the world's total energy produced which is 52% followed by the transportation sector with 26%. The energy consumed for residential and commercial sector are 14% and 8%, respectively (EIA, 2012).

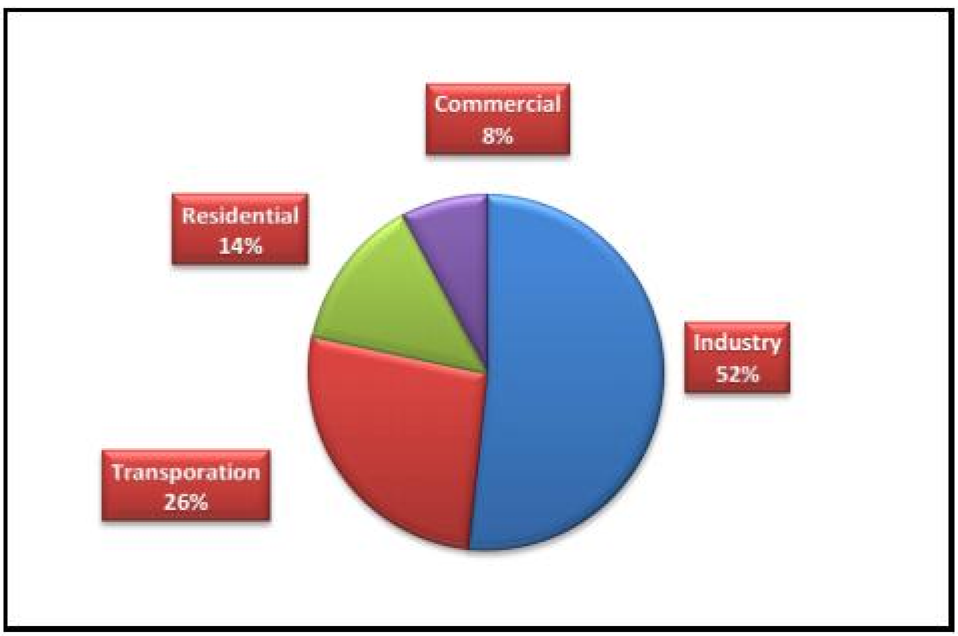


Figure: 2.1. Worldwide Energy Consumption (EIA, 2012)

The demand of energy in food industry and found that average product energy used is 9.8 MJ/kg and range of product energy used is 8.7 MJ/kg to 13.8 MJ/kg in pasta manufacturing industry. Cost of purchased fuels and electricity in 1994 for 20 selected industry sectors put for macaroni and Spaghetti industry as the cost of purchased electric energy was $15.9 million, and cost of purchased fuels was $5.3 million (Bureau of Census, 1994).

(Greenough and Fuentes, 2015); This paper describes a case study of an energy efficiency project carried out for a UK manufacturer of ready meals. The industrial processes used in the food industry vary between different facilities, but a small set of processes are responsible for most of the energy use. Low temperature heating processes dominate, accounting for 64% of all energy uses, while refrigeration and drying/separation are also significant at 7% each.

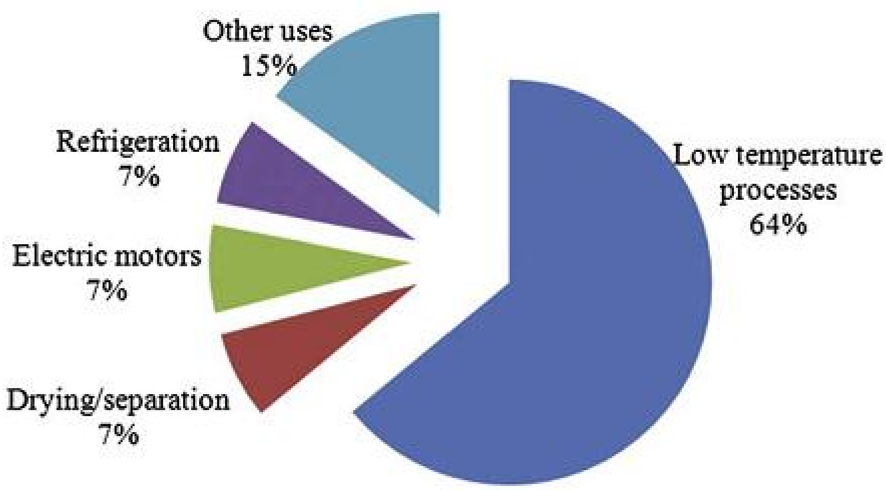


Figure: 2.2. Breakdown of food sector energy use

(Brunetti et.al, 2015); puts the monthly pasta production consists of 5846 kg of pasta, 175 kg of which is dry pasta and amount of used energy is 1100 kWh of electricity, 44.77 kWh of which used for dry pasta, 6231.8 kWh of thermal energy, 366.2 kWh used for production of dry pasta. Every kg of monthly produced pasta requires 0.18 kWh of electricity and 1.1 kWh of thermal energy.

(Wójtowicz and MoĞcicki , 2008); have conducted on pasta extrusion process and found the energy consumption was different for each raw material and its moisture during the extrusion and the specific mechanical energy values at the range from 0.07 to 0.13 kWh/kg during the extrusion-cooking of wheat starch. SME decreased with an increase in moisture content and extrusion temperature. The extent of reduction in SME due to an increase in moisture was lower at a higher temperature in feed materials. The observed SME values are 0.07 kWh/kg during processing of semolina pasta, with moisture content of 28% at 60 rpm and 0.45 kWh/kg when wheat flour type with moisture of 28% was processed at 120 rpm.

(Oyedepo et.al, 2015); This article presents an analysis of energy use and energy saving opportunities in selected industries in southwest Nigeria and studied the annual energy consumption and production output for the food processing industry are 5,452,467.24 GJ and 197,760 tons, respectively. On the average, the food processing industry has the highest energy consumption per year at 5,039.45 TJ/yr. Food processing and the manufacture of chemicals are complex and energy intensive, often requiring large quantities of thermal energy to convert raw materials to useful products. The Figure 2.3 justifies the electrical energy consumption in the food industry.

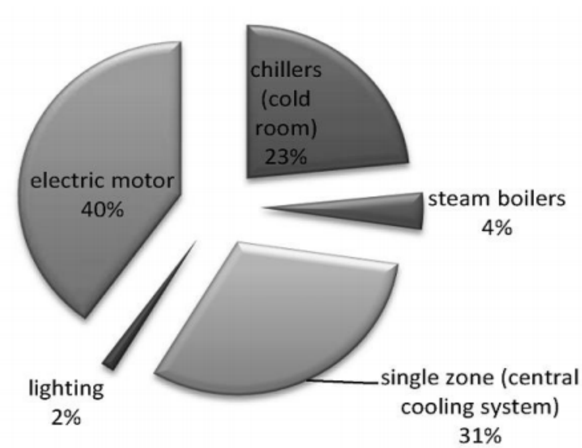


Figure: 2.3. Percentage of electric energy consumed by various equipments in the food industry

(Sattari et.al, 2007): identifies the energy saving opportunities of Iranian sugar factories after studied 17 sugar factories energy utilization. The energy intensity of sugar production were 34.6, 49.8, 24.7, and 10 GJ/ton respect to different production processes like sugar beet, cane sugar, beet and raw sugar, and raw sugar refining respectively. Thus, the average energy intensity among all factories was 27 GJ/ton. The alternative ways of electrical saving potentials were identified as using controllers on the fan's speed, appropriate use of electrical motors, and also utilizing high efficient motors will result in significant electrical saving. The amount of electrical savings is shown in the Figure 2.4 justifies the result.

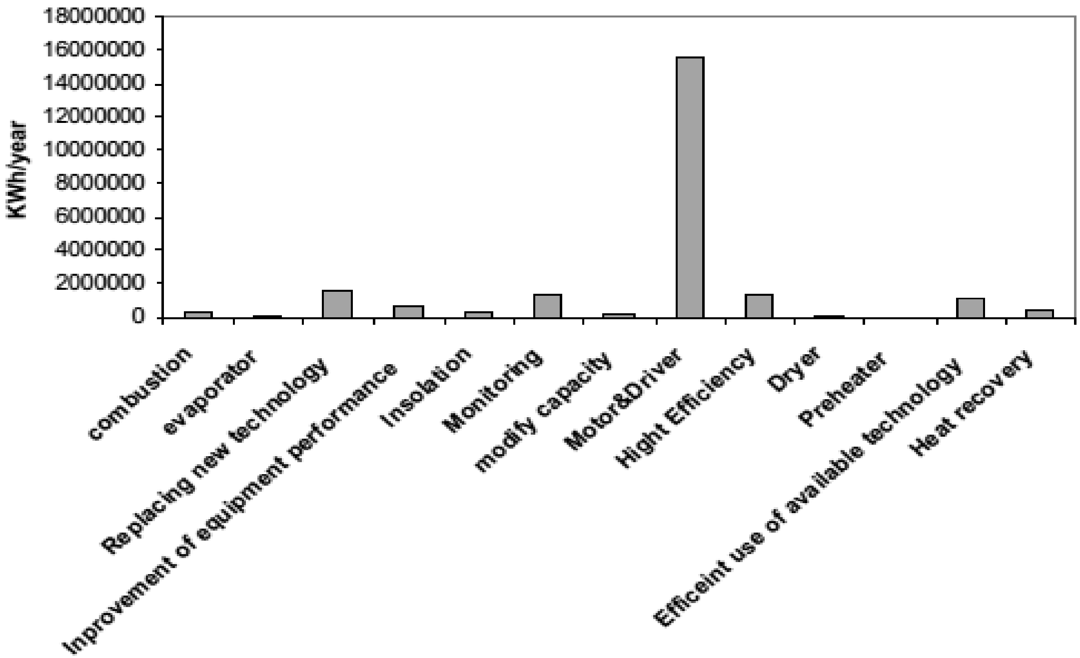


Figure: 2.4. Electrical energy saving potential

It was also identified the thermal energy saving potential in the sugar factories as in Figure 2.5 below.

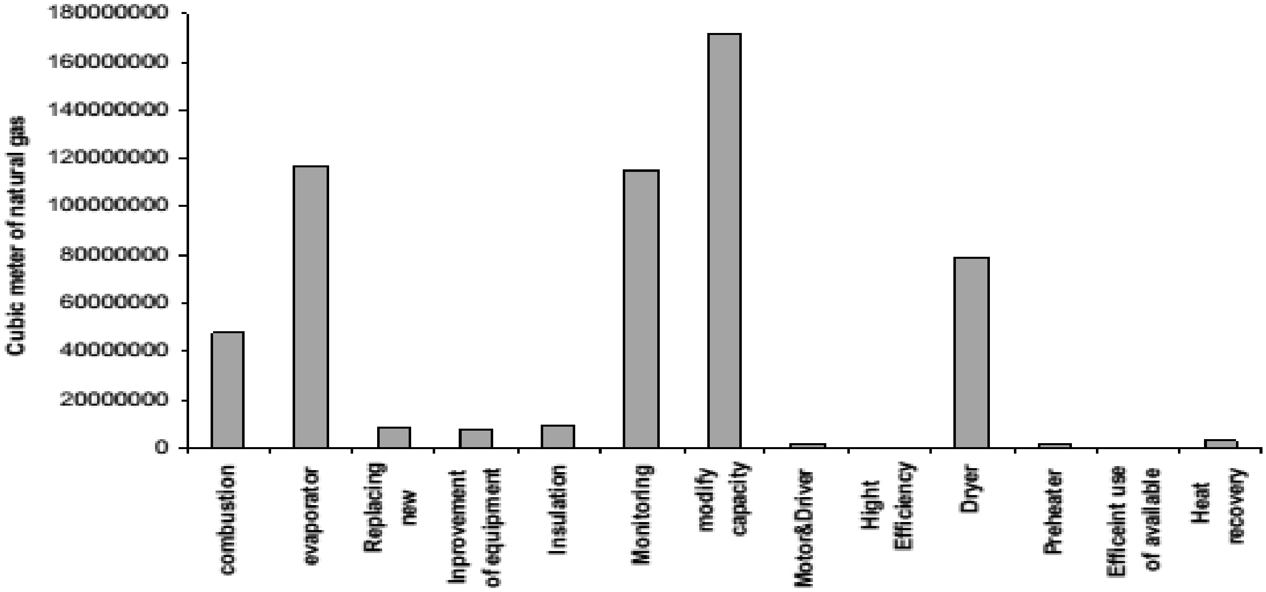


Figure: 2.5. Thermal energy saving potential

(Pandey and Prakash, 2018); the energy audit of a paper carton manufacturing unit was held in Indian pulp and paper industry and the specific electrical and thermal energy consumption was estimated to be 91.85 kWh/ton and 1619 MJ/ton paper respectively.

Annual energy saving potential was found to be 5.9% of the total annual energy consumption and the annual energy saving potential were represented as in the following Figure 2.6.

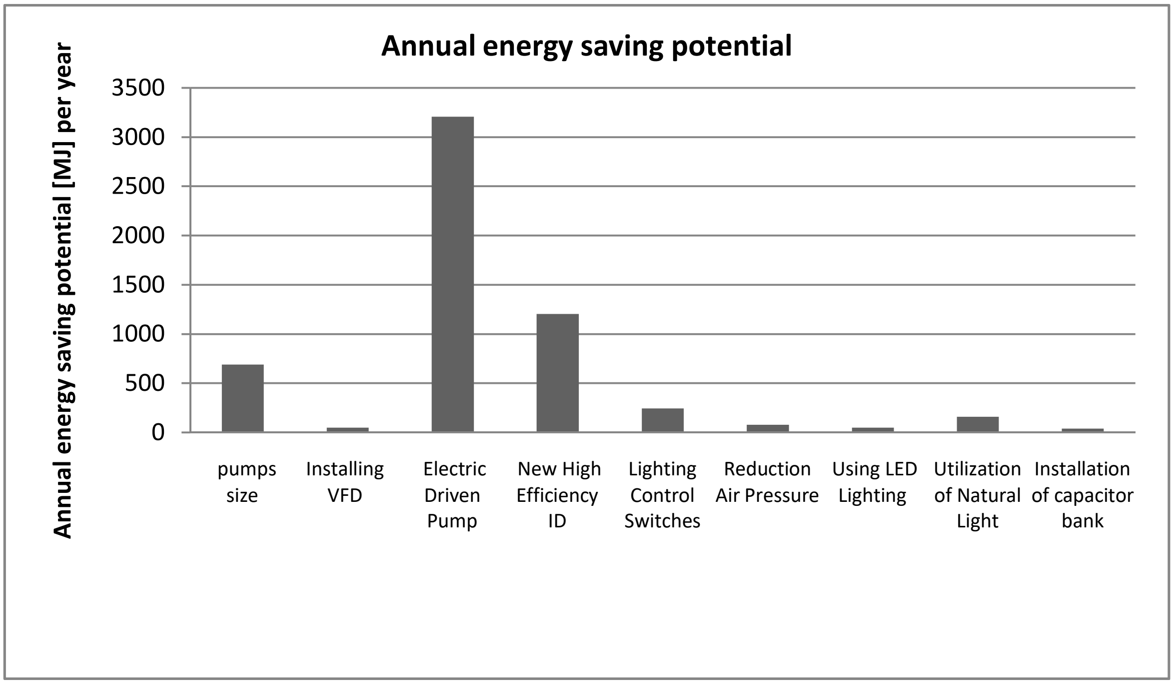


Figure: 2.6. Annual energy saving potentials in Indian pulp and paper industry

(Kanyama et.al, 2016); The study presented a survey of data for estimating energy requirements in the food Sector. As per the study, energy consumption for oil extraction was recorded as in the range of 0.28-1.5 MJ per kg output. Pasta fabrication requires about 0.8-2.4 MJ per kg output and drinks between 2.4-6 MJ per kg output. Reported energy use for sugar extraction (six observations) show a range of 2.3 - 26 MJ per kg output and fabrication of candy may require around 6 MJ per kg output.

(Masanet et.al., 2012); An energy audit revealed that a U.S. bread plant could reduce its electricity use by 35 MWh/year through the installation of high efficiency motors. At a cost of only $2,300, the occupancy sensors would save $4,500 per year and pay for themselves in only 6 months and high-pressure compressed air jets and air bars to clean bun pans after the baking step. Based on findings of a plant energy assessment, the plant has installed high-pressure blowers for pan cleaning to replace this energy-intensive use of compressed air. The measure is expected to reduce plant energy costs by nearly $16,000 per year.

At an investment cost of $9,000, the high-pressure blowers will pay for themselves through reduced energy costs in only 7 months and could reduce its electricity use by 58 MWh/year through the installation of a variable speed drive on its chilled glycol pumps. At a cost of $13,000, the new drive would save $7,400 per year and pay for itself in around 1.7 years. The two ovens in the plant with exhaust temperatures of about 650 °F, recommended installation of a heat exchanger on the oven exhaust stack to recover this waste heat and use it to preheat boiler feed water. At an investment cost of $25,000, the feed water preheating system would pay for itself through reduced natural gas costs in only 2.2 years.

Generally, the review of literature is done by focusing on the energy and related losses in the industry. Even if there are very little studies on quantifying the energy and loss saving potential on pasta industries by focusing on energy intensive equipments, the energy analysis and saving potential in different manufacturing industries, the performance analysis of different energy intensive equipment's were also reviewed. The annual energy consumption, specific energy consumption related with the product output of the industry was likely to survey. It is expected that the review results presented in this paper will create awareness on the potential energy savings of hot water boiler, electrical motors, water chillers system, compressed-air systems for industrial energy users.

2.2. Motivations for this work

It is clear that the industrial sector consumes more than half of the world's total energy produced which is 52% followed by the transportation sector with 26%. The energy consumed for residential and commercial sector are 14% and 8%, respectively (EIA, 2012). After a year worldwide industrial energy consumption is projected to grow from 51,69,7736 GWh in 2005 to 89,94,3511 GWh in 2040, Industrial Energy Consumption (EIA, 2013).

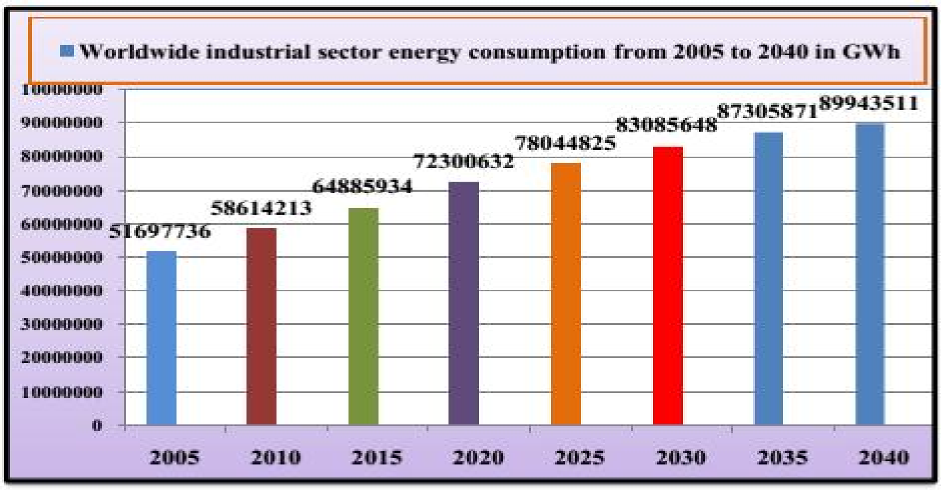


Figure: 2.7. Worldwide Industrial Energy Consumption (EIA, 2013)

In Ethiopia, the food processing industries are vast in numbers and also the energy demand and charges are increasing time to time. In Pasta and Macaroni factory, by focusing on energy related equipments, no study reported the specific energy index for the particular factory. Hence, there is an immediate requirement of exhaustive energy and emission investigation in the pasta and macaroni factory to develop the specific energy index. There are very few applications of numerical methods for the energy systems for energy and emission analysis in the industry. All the above facts have motivated me to take-up this research to investigate the energy performance, quantify the energy utilization and ways to conserve energy of the Pasta and Macaroni Factory for a case of Africa P.L.C.

CHAPTER 3

Description of pasta and macaroni production process in Africa plc factory

3.1. Industry profile

Africa plc is a profit based company established in November 1999 E.C for the purpose of engaging mainly in the business of food processing, with the initial capital investments of 5,000,000 ETB.

The company is owned by private share holder and over seen by the general manager Mr. Hussen Mohammed Nur. The total area of the company is $10{,}000m^2$. Currently Africa plc produces about 6 different shapes of Pasta and Macaroni. The company produces three pasta products; Buona, Roma, and Rosa and three shapes of macaroni products; Spiral, Big elbow, and Small elbow and wheat flour is another product of the company. In this company there are two milling houses, two pasta and two macaroni machines are found. Currently two Pasta and one Macaroni plants are working.

3.2. Pasta production

Pasta is a food product made by extruding and drying unleavened dough of wheat flour, and that forms the basis of much Italian cuisine, as well as Chinese, Japanese, Korean, and Southeast Asian cuisines. Dry pasta and noodles are products of any shape made from cereal flour with or without the addition of egg and or other ingredient by dough formation, shaping and drying without fermentation or baking process.

Fresh pasta is dried only superficially or not at all during the production process. Both types are sometimes treated with hot water or steam. In other expression pasta is made of two ingredients only semolina and water. These two ingredients are typically added to a continuous, high capacity auger extruder, which can be equipped with a variety of dies that determine the shape of the pasta. The pasta is then dried and packaged for market. In this pasta production certain requirements and conditions have to be fulfilled such as raw material, drying time, drying temperature, humidity, wheat flour and water flow rate.

3.2.1 Process description of pasta production

i. Flour inlet (cyclone)

The flour that comes from flour plant enters to the cyclone of flour. The cyclone has sight glass on which capacitive sensor is fixed that controls the amount of flour. Sensor makes an alarm when the flour at maximum and minimum level.

ii. Raw material and ingredient dozer

The first step in the pasta making process is raw materials dosage. Basic raw materials are; water, semolina (flour). A general control system controls flour by capacitive sensors. The water dozer pressure is within minimum of 1.5 bars and maximum 2.5 bars.

iii. Pre mixer

It is used to mix the flour and water by screws which are installed at the inlet of mixer and has a speed of around 45 Hz to increase the mixer efficiency. So at this time the entering wheat flour is mixed minimally with water.

iv. The mixer

After mixing, the dough transferred to the extruder by support of screw conveyer or by extrusion auger. The extrusion auger or screw conveyer is not only forces the dough through the die but it also kneads the dough in to a homogeneous, mass, control the rate of this production and directly influences the overall quality of the pasta finished product. The extrusion augers have shape edged because to create a uniform pitch over their entire length and augers. The augers fit in to a grooved extrusion barrel. This barrel helps dough move forward and reduce friction between the augers. Inside of the extrusion barrel a water cooling jacket are equipped to dissipate the heat generated during the extrusion process. This cooling jacket helps to maintain a constant extrusion temperature. If the dough is too hot, the pasta will be damaged. Uniform flow rate of the dough through the shaping extruder is needed. Then the dough pass through circulator head which is used to transported the dough in to the die and support the load of die machine by closing from upper and lower part of the head.

v. Dough kneading unit

In order to obtain an even and homogenous absorption of the liquids (water) by the flour particles (semolina or flour), at least two basic conditions have to be guaranteed:

- The particles must have the same size or average size ranging between not too distant minimum and maximum values.

- The time needed for the liquid to be absorbed by the particles has to be evaluated while taking in to account their average size and the temperature of both flour and liquid.

vi. Compressor screw

In the press, the extraction unit performs two functions, simultaneously; the kneading and pressing of the dough which is constantly feed by the mixer and mechanical function dealing with compression of the operating pressure usually included between 100 and 140 atm, and varies to the type of the materials employed and the shape of pasta. Inside the cylinder there is compression screw, which powered by a driving group formed by a motor and a reduction gear.

vii. The extruder

The final dough is extruded in the extrusion unit, consisting of a cylinder in side which a special extrusion screw turns. The screw rotation pushes the dough towards the head press on which a die is set. The pressure on the dough makes it to go through the openings in the die and get the required product shape. The dough extrusion is a complicated process that causes risk situations for both the product and the extrusion unit.

This occurs because;

- The pressure values are necessary high (on average 100 - 120 bar), and this can cause a mechanical stress to the dough, damaging its texture;
- The friction caused by the turning screw and the compression values produce heating that, if not kept under safety limits (usually <40 ℃) can cause thermal stress to the dough itself.

The heavy mechanical stress under which the extraction unit is kept (cylinder, screw head and their respective supports) requires control and safety devises to be accurate and timely. Manufacturers use extruder automatic locking devices that stop the unit in case the functioning values should exceed the safety standards (pressure, temperature).

viii. Pre die

This unit operation is used to shape the dough to cylindrical shape. Before entering the pre die the dough passes through the filter to separate the contaminants added during processing for the quality of final product.

ix. The die

The die function is to give the product three chosen shape. The great variety of pasta kinds and sizes is due to the possibility of making specific dies.

x. Pasta ventilation

As the product comes out from the die plate and before being spread on to sticks, receives the first ventilation treatment. This treatment helps the formation of a “skin” on the plate so as to prevent it from sticking up.

xi. The spreader

Once the dough is molded and got the required shape by the rectangular die, it will be laid on synchronized sticks by special unit called spreader. This unit function is to take the pasta curtain coming out of the die, to cut it off the right length and to place it on the stick that will bring the pasta curtain through the whole production line (pre-drying, drying, stabilization, possible storage).

Long cut pasta cannot carry out by a belt conveyor (as short cut pasta); this is not possible not only for the necessity of avoiding massing and stickiness, but above all for preserving its regular straight shape. As matter of fact, it has to be kept in a tidy position, side by side, held by a carrying stick so that it doesn’t stick together and especially, that it can be correctly dried. The use of sticks to carry long cut pasta through the whole production line requires a specific structure of the line itself and of the single stick moving system, with a complete synchronization between the different line parts.

The main spreader functional phases are as follows;

- Stick positioning under the die, in such a way as to make the pasta curtain slide as far as it has passed the stick for the required length,
- Pasta curtain folding on the stick, so that the remaining part of the curtain falls on the opposite side of the stick,

xii. Upper cutter

The pasta curtain is cut by a length wise shear while the synchronization guarantees that both folded sides of the curtain have the same length. At the discharge of the die the pasta has a moisture content of 33.8% and a blower immediately dries the surface of the dough strands in order to eliminate their stickiness just below the die, there is a rotating knife which cut the pre shaped strands to the desired length.

xiii. Lower cutter

A second shear makes a second next cut of both lower part of the folded curtain and perfectly trims all the pasta on the stick.

xiv. Scrap recovery

Presses for long cut or stamped goods production are provided with scrap recovery pneumatic device. This later collects fresh pasta trimming from spreader stamping unit and sent them to the mixer and are re-mixed in to the dough.

xv. Sticks return

The sticks return unit is installed under the line, in its whole length. Its function is collecting unloaded sticks by stripper cutter and of transferring them to the spreader.

xvi. The pre-dryer

Out of the die, pasta has about 33.8% moisture. Its surface has therefore the tendency to stick anything it may come in contact with (the stick and the other close pasta strings). In order to avoid this, pasta is exposed to hot and humid air ventilation already at the stick loading stage; in fact this ventilation causes a first reduction in the surface moisture, enough to avoid stickiness. Pre-drying is the pasta first drying phase after having been spread on to sticks. Pre-drying operation lasts about hour pasta being pre dried; it's mixing water content decrease of 60-70% and its humidity passes from 33.8% to 13.8 - 16%. This stage is characterized by the following technological situations:

- The product is heated to such temperature as to cause quick evaporation of the inside water;
- Pasta is kept at such room conditions (temperature & relative humidity)as to cause migration of the water particles from the inside to the outside of the product.
- It has to be avoiding surface pasta drying and the consequent closing of the interstices through which the remaining water can reach the surface by capillarity and evaporate.

xvii. The dryer

The second phase of pasta drying process occurs in this machine dryer, whereas as we have already seen the first phase of pasta drying takes place in the pre-dryer. Drying pasta means modulating and appropriately controlling the evaporation of water from the product, using heat and ventilation. In drying pasta, ventilation plays a fundamental role since besides removing the water given off by the product due to evaporation and is used as a vehicle to convey heat.

The heat energy conveyed by the ventilation air is used to heat the product and the water it contains, making it evaporate. Therefore, knowing the temperature of water required for a certain phase of the drying process and the time taken for the drying process is an essential condition for drying pasta correctly.

xviii. Cooler

At the end of drying, a cooling unit is always present in order to reduce the dry pasta temperature and to take it back to room temperature. The pasta cooling may take place in a specific section of the dryer or in a separate unit. The cooling is achieved by ventilation over pasta with cool humid air. The air temperature and humidity in ventilation are checked by special probes and controlled by modifying the water flow in the cooling batteries.

Like pre-drying and drying, a cooler has a set of centrifugal fans, radiators, and baffles for the purpose of cooling, but the difference is the temperature of the water that recycles for cooling i.e. 28 ℃.

xix. Packaging

Then after cooling the processed pasta is passed through intermediate storage by stick and dropped on the striping saw unit, the striping saw take from the stick load to belt. When the belt transports the pasta in to the cutting disc, the stick returns from previous place for again transportation the pasta that comes from the upper cuter. The cutting disc cut the pasta in to part then entered to vibratory loader which is used to create favorable loading condition for bucket elevator and create uniform flowing of pasta. The bucket elevator transports the pasta in to vibratory or dosing equipment. Then by passing vibratory the pasta entered to the scale tank.

At this stage by using scale tank, forming tube and guiding pipe the pasta will be create with uniform size and weight. Lastly, the arranged size and weight of pasta is pushed in to the longitudinal sealing machine which is used to pasta ready for packing. By using packing roller machine the pasta is packed by packing film and passes through transferring sealed pasta. Finally packed pasta is transport in to the intermediate storage house.

The production flow of long cut pasta is in Figure 3.1 in a block diagram.

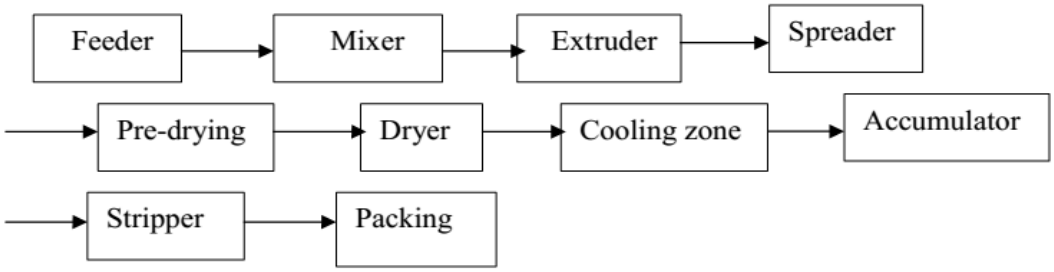


Figure: 3.1. Long cut pasta production flow

3.3. Macaroni production

Macaroni products are produced by mixing milled wheat flour with pure water. These macaroni production ingredients are typically added to a continuous, high capacity auger extruder which is equipped with a variety of dies that used to determine the shape of the macaroni. These macaroni process starts receiving semolina especially durum wheat type semolina because this wheat type semolina contribute for the final color, appearance and, shape of the macaroni. After receiving mixing wheat flour with water then sizing or kneading the macaroni transported in to drying section. The entered macaroni with specific humidity, drying temperature and drying time will be dried then it entered to the cooling section. The macaroni will cooled finally packaged then manually transferred in to intermediate storage. In this macaroni production machine the company produce three different shape of macaroni product. These are spiral, big elbow, and, small elbow macaroni. The differences of these three macaroni products are only by the shape and size of the macaroni.

3.3.1 Process description of macaroni production

First the macaroni production starts receiving semolina flour by pneumatic pipe from the wheat flour milling house. This incoming wheat flour entered in to flour cyclone.

The flour that comes from flour plant enters to the cyclone of flour. The cyclone has sight glass on which capacitive sensor is fixed that controls the amount of flour. Sensor makes an alarm when the flour at maximum and minimum level.

Then load on air lock, by air lock the flow of flour balanced and dropped on the screw conveyer that conveys the incoming wheat flour entered to the pre mixer machine. On this stage the flour minimum mixing from the entering water by water pumps then the minimum mixing of wheat flour and water transported in to maximum mixing machine means entered to the mixer. In this mixing machine water is added to produce dough or create dough formation. On this stage by using vacuum chamber remove air bubbles from the macaroni dough before extruding. But if it is not removed the air bubbles or the dough create small bubbles in the macaroni will loss the mechanical strength and finally the product color will be changed in to a white color, and chalky appearance.

After mixing the dough transferred to the extruder by support of screw conveyer or by extrusion auger. The extrusion auger or screw conveyer not only forces the dough through the die but it also kneads the dough in to a homogeneous, mass, control the rate of this production and directly influences the overall quality of the macaroni finished product. The extrusion augers now have shape edged because to create a uniform pitch over their entire length and augers. The augers fit in to a grooved extrusion barrel. This barrel helps dough move forward and reduce friction between the augers. In the inside of the extrusion barrel are equipped with a water cooling jacket to dissipate the heat generated during the extrusion process. This cooling jacket helps to maintain a constant extrusion temperature. If the dough is too hot the macaroni will be damaged. Uniform flow rate of the dough through the shaping extruder is needed. Then the dough pass through rectangular head which is used to transported the dough in to the die and support the load of die machine by closing from upper and lower part of the head.

Before dying or shaping process present impurity of dough is filtered or removed by filter or screening equipment. After screening the dough pass through pre die. This pre die creates favorable shaping condition to the next die or shaping process. The dough again passes through the die equipment. At this stage the macaroni dough will form a uniform or desired shape of macaroni then by cutting machine the shaped macaroni will cut and entered to the hopper for intermediate storage of macaroni. But on this step the macaroni have contain little content of moisture. So it will create stickiness from another cut and shaped macaroni.

By ventilation machine, some content of moisture will be dry and pushed to the hopper by creating hot air blown.

The macaroni transported in to shaker which is used as pre drying of macaroni since it reduces the moisture content the macaroni. Then the macaroni entered to the bucket elevator, by this elevator the processed macaroni is transported on the vibrator. The vibrator creates a uniform distribution in to the drying section. After vibrator, the macaroni dropped in to dryer. This dryer have 9 tiers which is used in drying process to transport the processed macaroni from 9 tiers to 1 tier. The main objective of drying is to lower the moisture content of the macaroni from 33.8 to 12 %. In this moisture gap the finished product will be hard, retain its shape and can store without spoiling. So at this processing stage most of the moisture that present in the macaroni product must be removed to get the final desired product of macaroni. The macaroni will be humidified and dried by ventilation machine which is used to in drying stage to dry and humidify the macaroni. Then after dried macaroni is entered to the cooling section by using ventilation machine the macaroni will cool. Immediately, the finished macaroni is transported and dropped in to the belt elevator by using vibrator. The belt conveyer is again transported and dropped on the hopper. Then it passing through the hopper entered to the weighing machine. After weighing the macaroni is bagging by packing bag and manually sewing by sewing machine finally manually transferred in to the intermediate storage house.

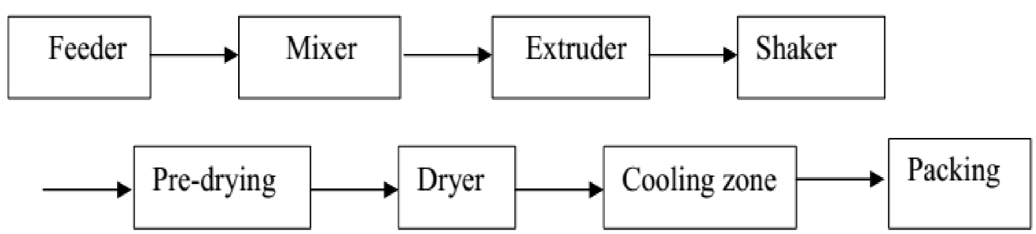


Figure: 3.2. Macaroni production flow

3.4. An overview of the drying process

Before going too far into the details about drying, it needs to look at how moisture is removed during a typical drying process. The concepts applied here will be applicable to the majority of other materials that we encounter in our drying work. Rather than trying to discuss everything in totally general terms, it might be easier to use some specific material.

3.4.1. The drying mechanism

Most products dry because moisture (which is really water) is removed from their surfaces. It is important that the air used for drying purposes is not overly humid, or saturated with moisture. When warm dry air is blown across the surface of the wet material, it picks up some of the moisture by the process of evaporation. Evaporation is the change that occurs when water goes from being a liquid to a vapor. So, the warm air now contains water vapor and carries it out of the dryer and away from the material.

As more and more air blows across its surface, moisture from inside the material comes to the surface to replace the moisture that was lost. This process of moisture moving from the centre of the material to the outer surface is called “diffusion”. Moisture that has diffused to the surface is then evaporated and swept away by the moving air.

At the start of the drying process, the combination of a wet surface and additional moisture coming to the surface makes the rate at which the water is removed quite high. The drying process occurs when the moist pasta are first placed in the dryer.

The surface is considered to be saturated with moisture which is like having a “pool” of moisture there from which evaporation can take place. Moisture evaporates from the “pool” at a uniform or constant rate. Eventually, a point will be reached where the surface no longer looks wet, since there is no visible moisture present. Moisture will still be travelling from the centre of the pasta to the surface, but it will be removed as soon as it gets there.

As more and more moisture is removed, the rate of water removal gets slower and slower.

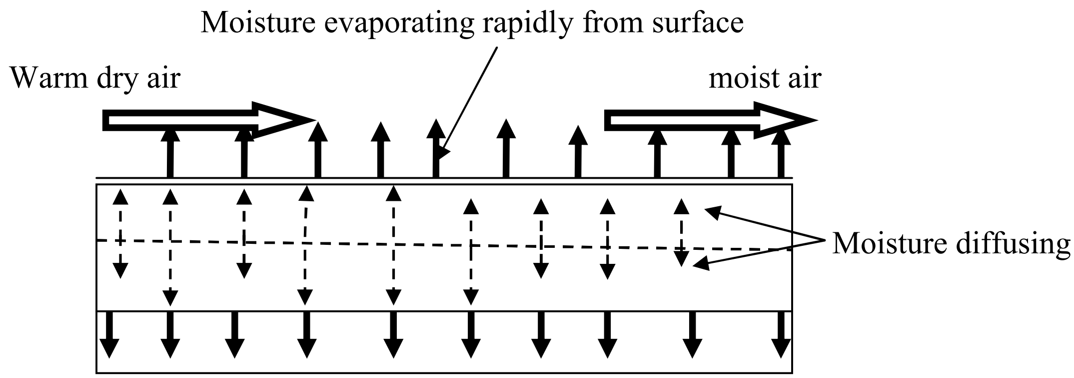


Figure: 3.3. Moisture removal from the surface of pasta during the early stages of drying

3.4.2. Convective drying

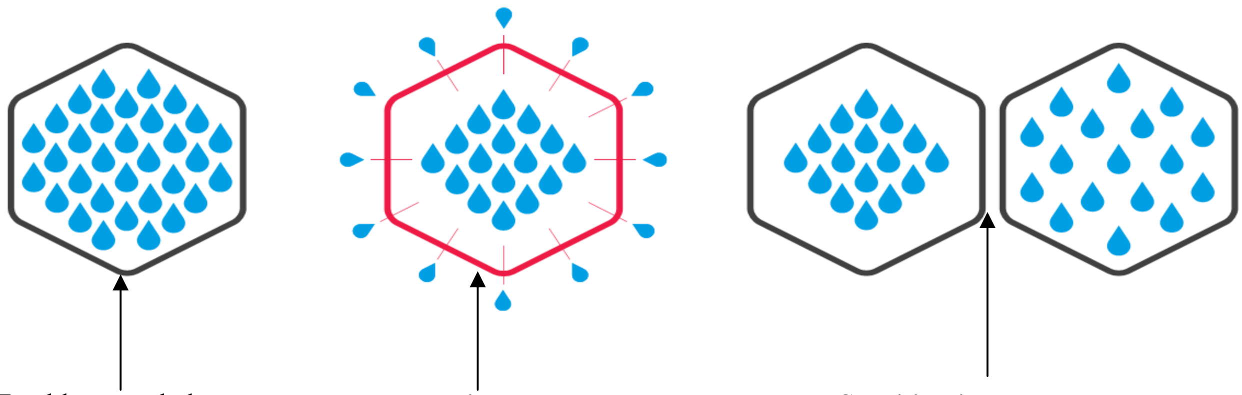
Convective dryers are the most widely used devices to dehydrate agricultural products In this process, several heat and mass transfer mechanisms occur but, diffusion within the product is considered as the dominant factor controlling moisture transfer from inside of the product to its surface. Then, the water is transferred from the product and air interface to the air stream by convection.

The convective drying systems are aimed to establish atmospheric conditions in which evaporation would be promoted. Thus, convective dryers aim to reduce the level of air humidity by decreasing the air temperature. All convective drying systems can be conditionally divided into two types: convective heat dryers which use air as the heat transport agent, and those which use fluids for transporting heat. In the systems which use fluids for transporting heat, the respective fluid is heated up and conveyed to the heat exchangers installed in the system. The liquid convective drying systems effectively concentrate heat energy in particular sections within facilities, but they require the installation of separate exhaust systems conveying heated air to the ambient atmosphere.

Air convective dryers ambient air is heated up in a heat exchanger, and thereafter passes through flexible tubes. The built-in exhaust system carries the heated air together with the evaporated moisture off the system.

Tier dryers are a type convective dryer which contain a special perforated belt unit which is used for moving the dried material inside the machine. Heated air circulates under, over and through the tier belt. Most often, the unit is divided into special zones, and the heated air treats those zones in different ways, respectively. Different temperatures can be applied in different zones as well.

Applying the same principles on pasta processing industries removal of moisture is observed as follows.



Freshly extruded pasta
Contains approximately 33.8% water

Drying area
The first drying stage dries the outer layers.

Stabilization area
The moisture is concentrated in the heart of pasta. The water is able to distribute itself uniformly in this zone with a lower temperature and higher humidity level.

Figure: 3.4. Gradual removal of moisture

The constant rate drying time is inversely proportional to the gradient of humidity ratios at the product surface and in the heated air. Thereafter, the air is reheated and re-circulated, while part of the air with moisture content is exhausted to the atmosphere.

The recycling of process air ensures a high level of the tier dryers' cost-effectiveness. Major limitations in the operation of tier dryers include the possibility of unit clogging, and difficulties with belt maintenance.

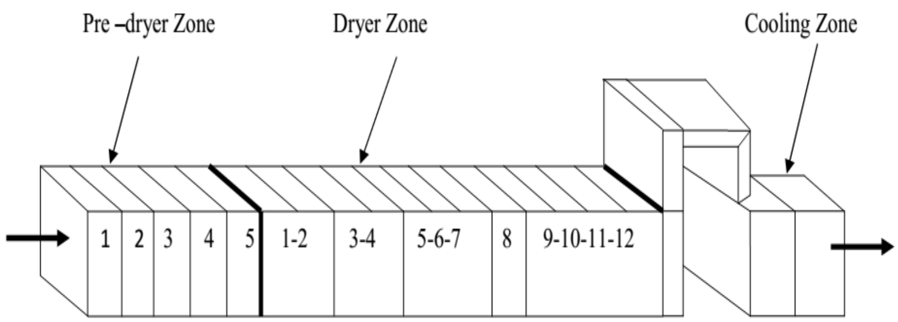
Industrial manufacturers of dry pasta use machines called "dry pasta lines" to make high volumes of product. Long goods dry pasta lines make long pasta, such as spaghetti and linguini, and short goods pasta lines make short pasta. A typical dry pasta line consists of an extruder, dryer and packing system, which are positioned linearly in a row thus forming a "line" of interconnected machines.

3.4.2.1. Long cut pasta production flow and drying mechanism

The spreader hangs the strands of long pastas on the metal sticks where heated air flow is blown to prepare the product for high temperature. Pre-dryer reduces the moisture quickly (from 33.8% to 18%) in about an hour. Heat is produced by hot water radiators and centrifugal fans. For the first phase of the finish drying, product goes into a dryer with multi rows of hot water circulation heat exchanger. This phase decreases high rate of moisture and pasteurized the product.

In the second phase warm air are blown to the product in an isolated multi unit dryer and remove the excess moisture**.**

Wet pasta



dried pasta

Figure: 3.5. Long cut pasta drying mechanism

3.4.2.2. Macaroni production flow and pasta drying mechanism

Short pasta pieces fall on the shaker conveyor and hot air is blown to them immediately after the extrusion. This reduces the moisture content and prevents the pieces from sticking and flattening. Shaker then carries the product through tiers with dry hot air and buckets collect the pasta and spread them on the upper tier of the multi-tier drying unit.

This unit has different zone which periods of intense moisture extraction alternately followed by periods of rest occur drying/stabilizing cycles in total. Process ends in cold air chamber for stabilizing.

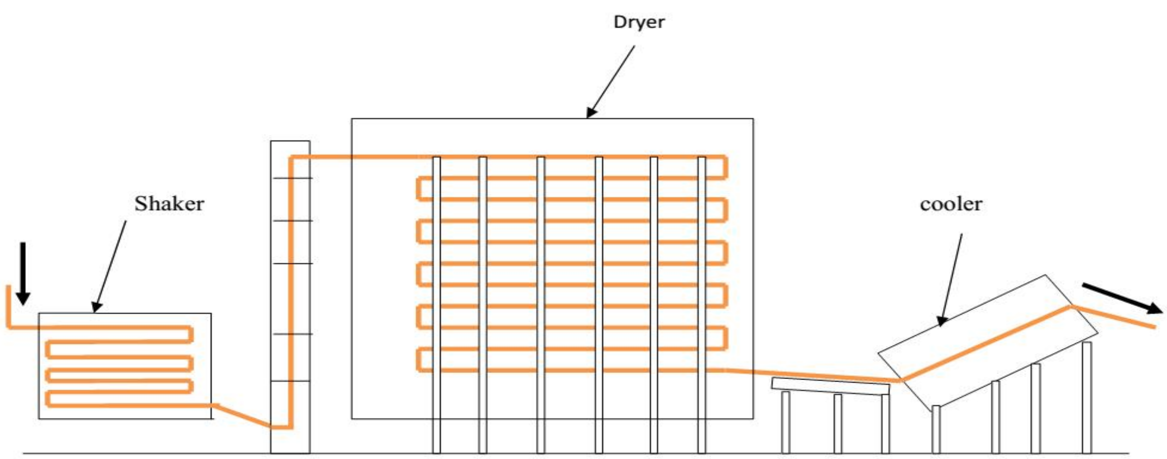


Figure: 3.6. Macaroni drying mechanism

CHAPTER 4

Energy and Utility System Description

4.1. Thermal energy

There are equipments or systems that produce, convert, transfer, distribute or consume thermal energy.

4.1.1. The factory's fuel demand reviews

The following data describes fuel quantity demand and its cost of the factory of 2009 and 2010 E.C. As it is seen the fuel demand was within range of 41- 96 m^3 of 2009 and 44- 68 m^3 of 2010 E.C.

Table 4.1.The factory's fuel demand and cost review of 2009 and 2010 E.C

	Fuel quantity in [m^3]		Fuel cost in ETB[Million]	
Months	2009 E.C	2010 E.C	2009 E.C	2010 E.C
January	41	66	0.59	1.07
February	66	66	0.94	1.07
March	67	51	0.96	0.84
April	46	66	0.66	1.07
May	66	47	0.95	0.76
June	96	47	1.38	0.76
July	63	49	0.90	0.80
August	67	48	0.96	0.78
September	65	68	0.93	1.11
October	44	66	0.64	1.07
November	68	46	0.98	0.74
December	66	44	0.95	0.72

The fuel demand is varied from month to month. It can be summarized as in the following graph.

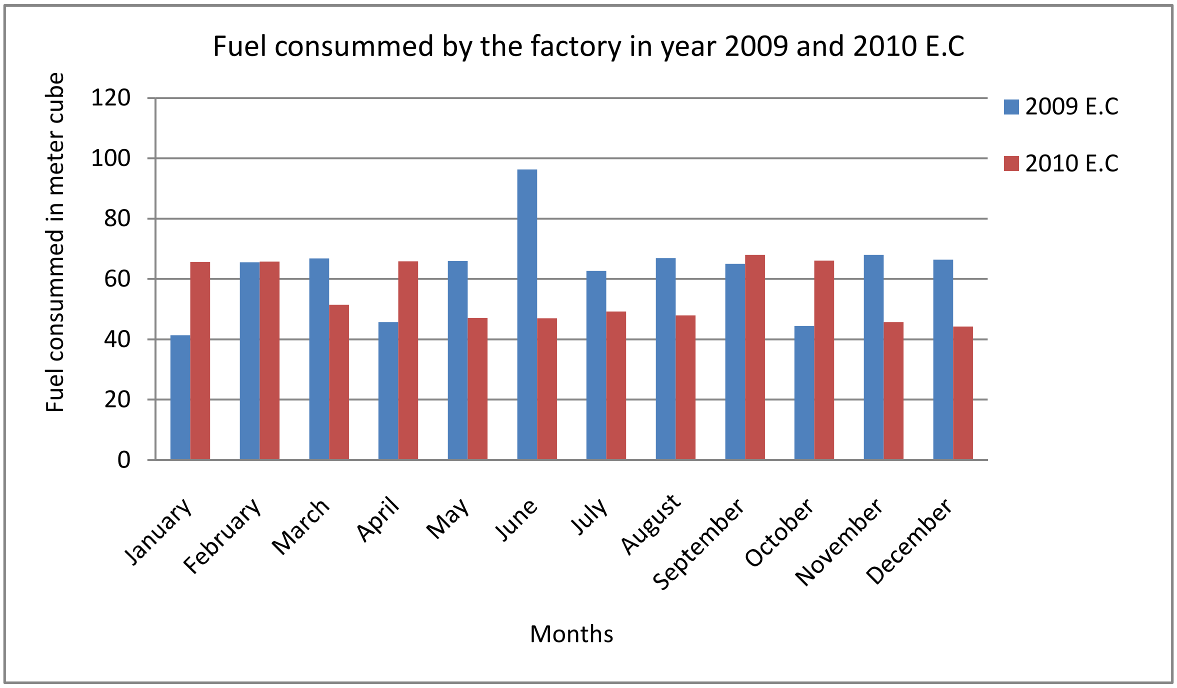


Figure: 4.1. The company's two year fuel consumption

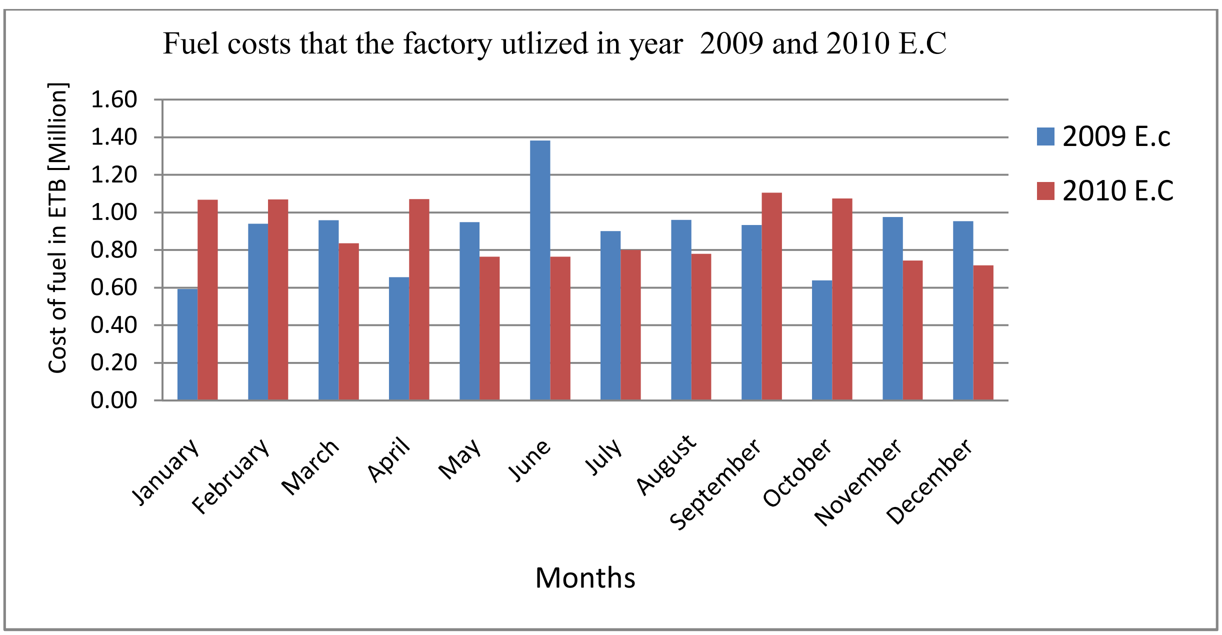


Figure: 4.2. The company's two years fuel cost

4.1.2. Current status of the factory's fuel consumption

To know the current (2011) actual fuel consumption of the factory, the measurements are held at different 8 days from different 8 months with there respective sessions of a day were mesuared and the minimum and maximum results were identified as 2785 liters and 3447 liters respectively.

Table: 4.2.Current fuel consumption of the factory

Days	Session 1[L]	Session 2[L]	Session 3[L]	Total [L]
8-Jan	905	908	1257	3070
13-Feb	796	966	1339	3101
4-Mar	892	955	938	2785
9-Apr	1296	1091	1060	3447
19-May	858	1266	1101	3225
25-Jun	945	1191	935	3071
22-Jul	917	1247	922	3086
10-Agust	925	1150	1055	3130

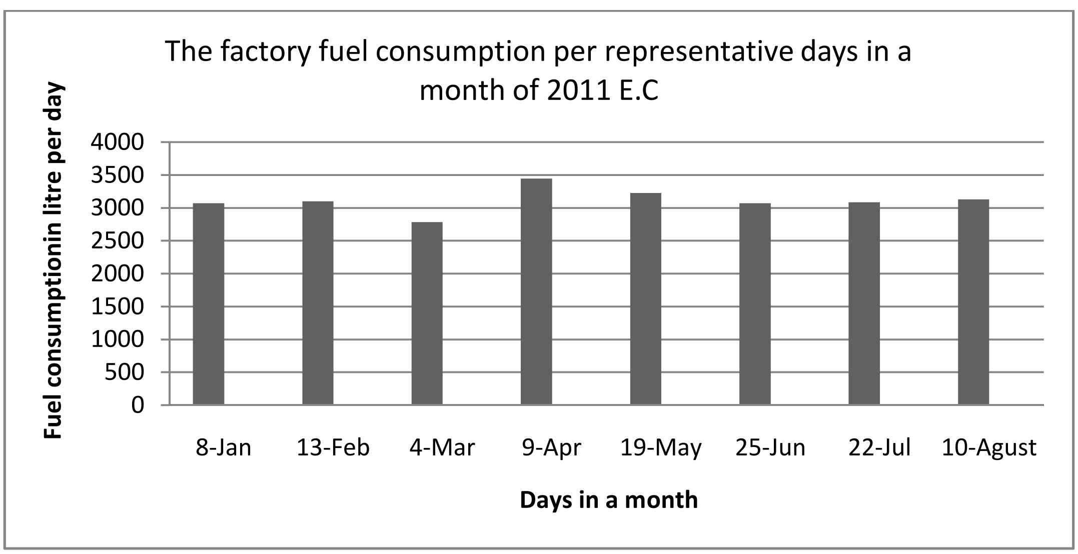


Figure: 4.3. Average fuel consumption per day (2011 E.C.)

4.2. Electrical energy

Electrical energy constitutes a major energy center in the Pasta and Macaroni factory for a case of Africa P.L.C. Investigation of energy performance through energy audit explores the total electrical system from the electrical power consumption data of equipments of observed mechanical load. A listing of equipments consuming electrical energy was made and categorized into three basic sections for pasta and macaroni production process in the company

- Utility section
- Production process section
- Lighting

In the utility section the electrical energy consumption is due boiler pump motor, chiller pump motor, and utility pump motor. With in production process and drying units, air inlet fans for generating hot air through a heat exchanger, any additional cold air injection fan or recirculation fans and exhaust fans, any pumps or material recirculation arrangements or conveyor (band) drive, air compressor and water chiller machines consume electrical energy.

4.2.1. Electrical power utility and distribution system

The electrical power distribution in the company is indicated in Figure 4.4.

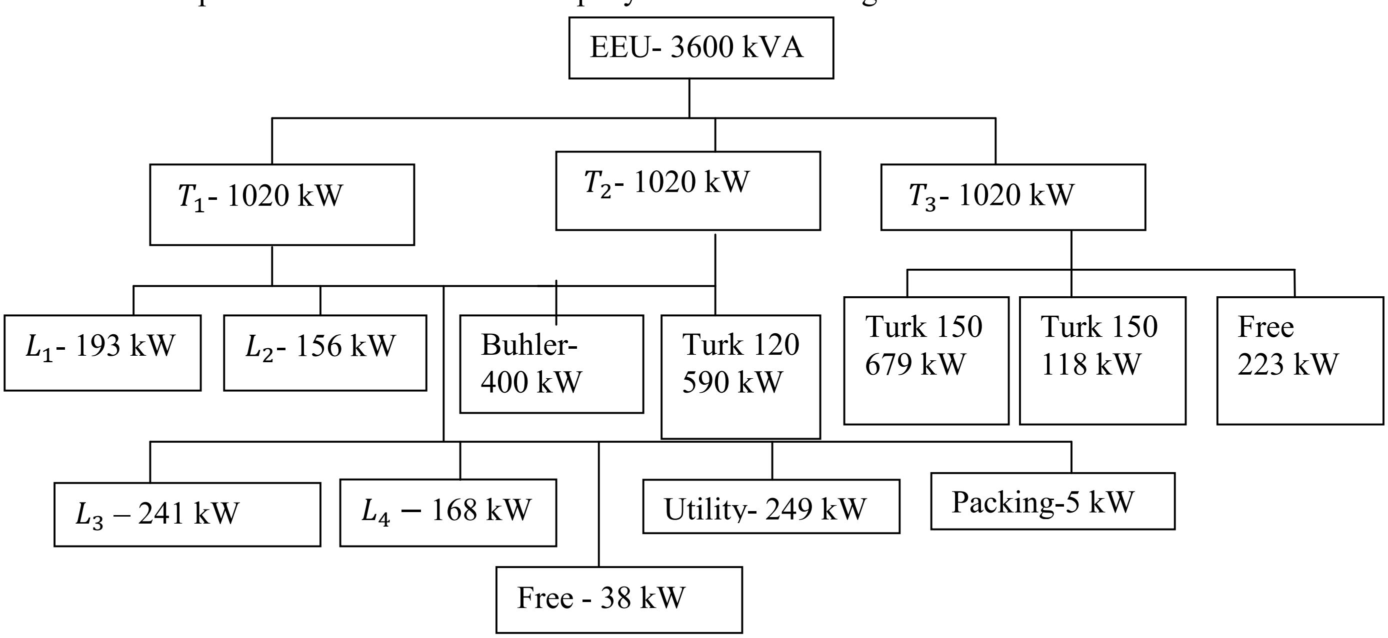


Figure: 4.4. Company's electrical power distribution system

4.3. Air compressors system

Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs. Use of compressed air in industry and in service sectors is common as its production and handling are safe and easy. In most industrial facilities, compressed air is necessary to manufacturing.

The air compressors which are used in the Pasta and Macaroni factory for a case of Africa P.L.C are studied. The capacity of the air compressor, and the power consumption during loading and unloading were measured. The time taken for loading and unloading is also noted.

The African P.L.C is used GX (7 and 11) air cooled, double stage, oil injected screw compressors which are driven by an electric motor. The compressors are belt driven and enclosed in sound insulating body work. Air drawn through filter and open inlet valve into compressor element is compressed. Compressed air and oil flow into oil separator/tank. The air is discharged via minimum pressure valve towards the air outlet.

Air pressure forces the oil from oil separator/tank through oil cooler and filter to compressor element. In oil separator/tank, most of the oil is removed centrifugally. The remaining oil is removed by oil separator. Wet compressed air enters the dryer and is further cooled by the outgoing, dried air. Moisture in the incoming air condenses. The air then flows through heat exchanger where refrigerant evaporates, withdrawing heat from the air. The cold air then flows through condensate traps which separate condensate from the air. There are 3 compressors installed in the plant to cater the compressed air requirement of the plant. Compressed air required for the pneumatic applications of the machines. Set pressure points for the plants are 6-10 bars. Compressed air is a versatile and safe media for energy use in the plants.

A typical compressed air generation, distribution and utilization diagram is given in Figure 4.6 below.

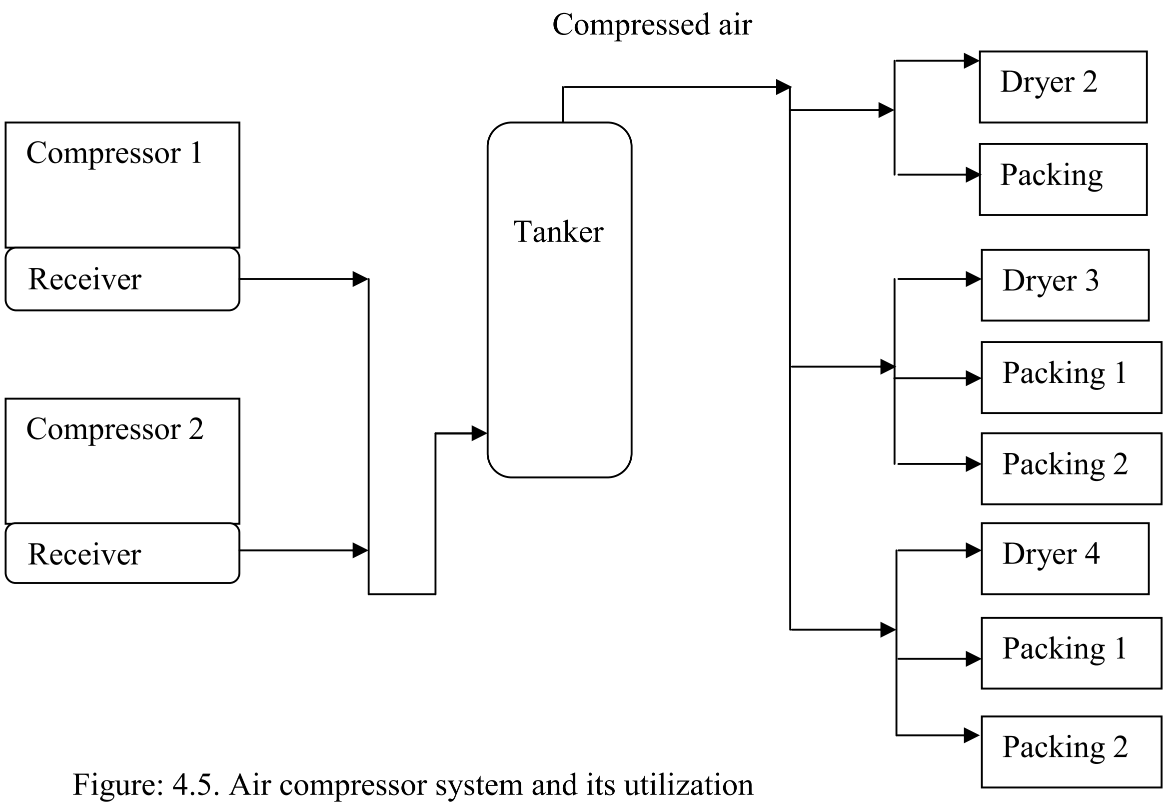


Figure: 4.5. Air compressor system and its utilization

The electrical energy analysis and consumption of the air compressor is conducted in chapter 8.

4.4. Water chillers' utility system

Water chiller is one of the common utility demands in industry. Chilled water systems consist of these functional parts:

- Chillers that cool the water or fluid
- Loads, often satisfied by coils, that transfer heat from air to water
- Chilled water distribution pumps and pipes that send chilled water to the loads
- Condenser-water pumps, pipes, and cooling towers or condenser fans that reject heat from the chiller to ambient air
- Controls that coordinate the operation of the mechanical components together as a system

In most cases, the chiller's purpose is to make water colder. Some chillers cool a mixture of water and other chemicals, most commonly added to prevent freezing in low-temperature applications. The chiller rejects the heat extracted from the chilled water, plus the heat of compression (in the vapor compression cycle), or the heat of absorption (in the case of an absorption chiller) to either the ambient air (air cooled) or to another circuit of water (water cooled). If the compressor motor is refrigerant cooled, the chiller also rejects heat generated by motor inefficiency. Air-cooled condensers use fans to facilitate cooling by the ambient air. Water cooled condensers typically use an evaporative cooling tower.

After the water has been chilled, it is distributed via pumps, pipes, and valves (the distribution system) to the loads, for cooling zone of heat exchanger where transfers heat from the air to the chilled water, which is returned to the chiller. Each section is equipped with the separate Chiller. There are total of 3 chillers installed in the plant out of which only 2 were working and the rest was stand by.

All the end use of cooling water with flow quantities should be indicated in the diagram Figure 4.7.

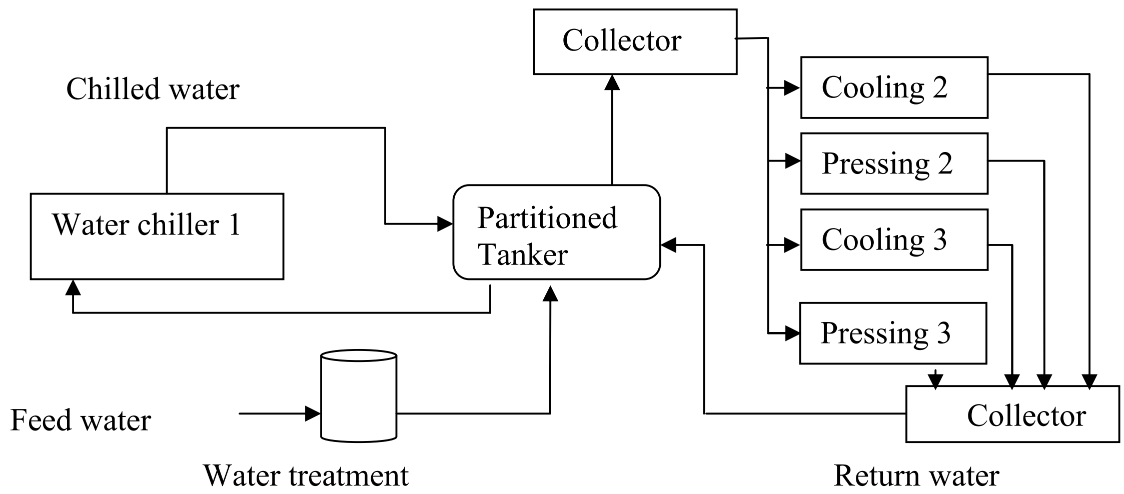


Figure: 4.6. Water chiller-1 and its utilization

Water chiller-2 feeds the chilled water to production plant-4 of pressing section to cool the heat generated during pressing (Figure 4.8).

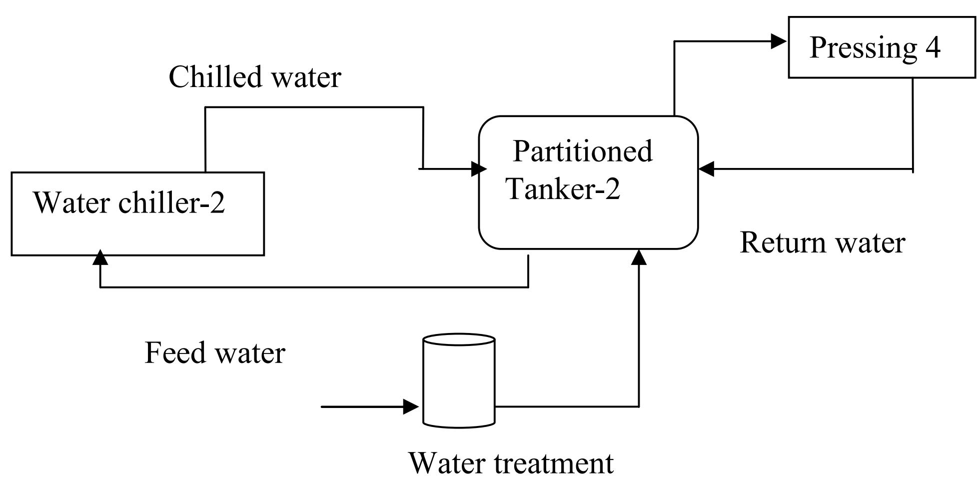


Figure: 4.7. Water chiller-2 and its utilization

The electrical energy analysis and consumption of the water chiller is conducted in chapter 8.

The summary of the utility plant layout of the factory is shown in Figure 4.8.

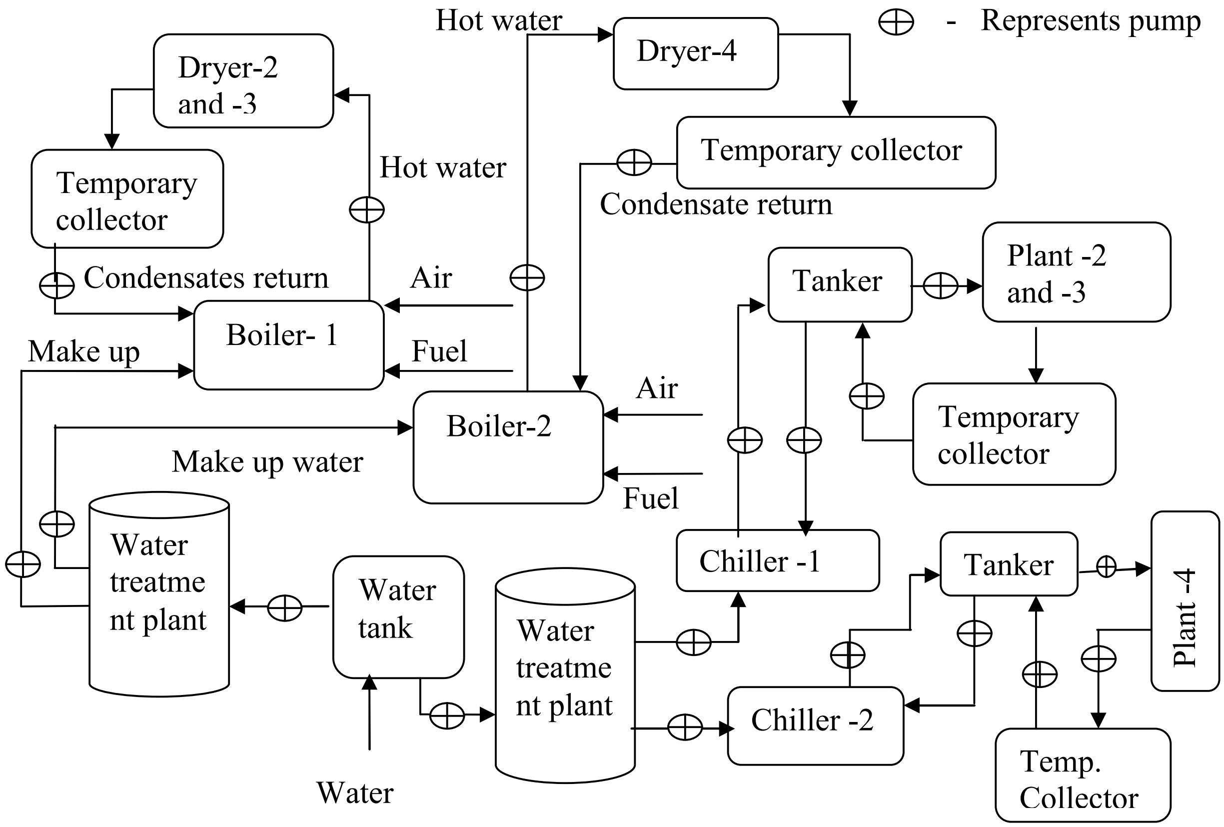


Figure: 4.8. Utility plant layout

In figure 4.8 above the tanker is partitioned/separated for not to mix cold and hot fluid.

CHAPTER 5

Energy Analysis of Hot Water Generation and Distribution System

5.1. Hot water generation

A boiler is a device that converts the chemical energy of a fuel into a useful heat output. Inside a boiler, the fuel is combusted by burners. These produce flames, and the hot combustion gases created transfer the heat to water, which has been fed into the boiler from an external source. Fire tube or "fire in tube" boilers; contain long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to hot water circulates.

Figure: 5.1. Boiler used at the factory.

Hot water generated from fuel firing is used for feeding the dryer. The heat input to a dryer is derived from the quantity of fuel consumption, stoichiometric and excess air input for combustion, fuel analysis and GCV/NCV of the fuel and thermal efficiency of combustion. The hot water and condensate water circulation held in between the boiler and the dryer section at which the heat from hot water is transferred in to fresh air to make hot air which is blown to the drying chamber.

After drying is taking place the condensate water is circulated to the boiler (Figure 5.2).

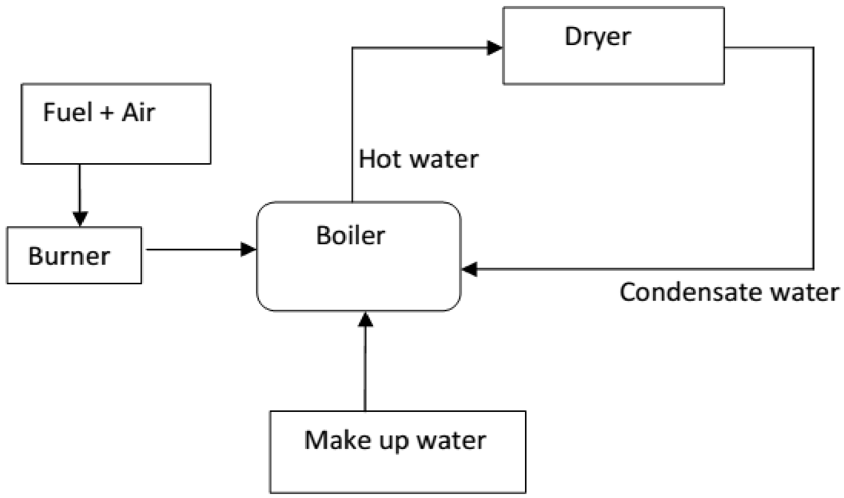


Figure: 5.2. Hot water circulation in the company (closed type)

5.2. Fuel consumption and heat output

The heat input to a dryer is derived from the quantity of fuel consumption, stoichiometric and excess air input for combustion. If combustion gas output is to be known, the efficiency of combustion was estimated by loss method and the amount of excess air and stoichiometric air was found from fuel analysis and averaged oxygen content in flue gases. This procedure will entail the thermal efficiency test in addition to the dryer test.

$$Q_{in} = \dot{m}_f * \text{GCV} * \eta_b \quad (5.1)$$

Where, Q_{in} - Heat input to dryer, $\dot{m}_f$ - fuel Consumption, GCV - calorific value of the fuel and η_b - thermal efficiency of combustion

5.3. Energy performance assessment of boilers

Energy performance assessment of boilers efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. Any observed abnormal deviations could therefore be investigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry.

The purpose of the performance test is to determine actual performance and efficiency of the boiler and compare it with design values or norms. It is an indicator for tracking day to day and season to season variations of boiler performance.

The efficiency of a boiler is quoted as the percentage of useful heat available, expressed as a percentage of the total energy potentially available by burning the fuel. In this study the complete heat balance was done using indirect method.

Basically this study was used indirect method to evaluate boiler efficiency by considering different loses with the reference standards for boiler testing at Site using indirect method USA Standard, ASME PTC-4-1 Power Test Code Steam Generating Units'. The following losses were expected to consider in this study to determine boiler performance

1. Loss due to dry flue gas (sensible heat)
2. Loss due to hydrogen in fuel (H_2)
3. Loss due to moisture in fuel (H_2O)
4. Loss due to moisture in air (H_2O)
5. Loss due to carbon monoxide (CO)
6. Loss due to surface radiation, convection and other unaccounted.

5.4. Energy performance assessment of fire tube boilers

The hot water boiler efficiency has a great effect on heating which is related energy savings. It is therefore significant to maximize the heat transfer to the water and minimize the heat losses in the hot water boiler. To optimize the operation of a hot water boiler plant, it is essential to specify where energy waste is likely to occur.

The following parameters were measured, as applicable for the computation of hot water boiler efficiency and performance.

Flue gas analysis

- Percentage of CO_2or O_2 in flue gas
- Percentage of CO in flue gas
- Temperature of flue gas

Temperature measurements for

- Flue gas
- Hot water
- Makeup water
- Condensate return
- Fuel

In order to calculate the boiler efficiency by indirect method, all the losses that occur in the boiler were established (Lahijani et.al., 2017), (Harim et.al., 2008), (Barma et.al, 2017) , (Virendra et.al., 2013), (Sachin et.al, 2014). These losses are conveniently related to the amount of fuel burnt. It was observed that there are four boilers in the factory, two were working and the others were standing by. In this study the two working boilers performance test were assessed separately to identify likely occurred losses and its energy saving opportunities.

Theoretical (stoichiometric) air fuel ratio and excess air supplied were determined for computing the boiler losses. Using the measured values, they were estimated through (Lahijani et.al., 2017), (Sachin et.al, 2014).

a) Theoretical air required for combustion (Sachin et.al, 2014)

$$RA = [(11.6 \text{ x } C) + \{34.8 \text{ x } (H_2 - O_2/8)\} + (4.35 \text{ x } S)]/100 \qquad (5.2)$$

b) Theoretical air required for combustion (Sachin et.al, 2014)

$$RA = [(11.6 \text{ x } C) + \{34.8 \text{ x } (H_2 - O_2/8)\} + (4.35 \text{ x } S)]/100 \qquad (5.2)$$

c) Actual mass of air supplied/ kg of fuel

$$AAS = (1 + EA/100) \text{ x theoretical air} \qquad (5.4)$$

The various losses associated with the operation of boiler were discussed below (Lahijani et.al., 2017), (Sachin et.al, 2014).

1. Heat loss due to dry flue gas (%)

This is the greatest boiler loss and can be calculated with the following formula:

$$L_1 = \frac{mxC_px\,(T_f - T_a)}{GCVoffuel} \text{ x } 100 \qquad 5.5)$$

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 ℃

T_a = Ambient temperature in ℃

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

The losses due to water vapor produced from Hydrogen in fuel, moisture present in fuel and air during the combustion were not been included in the dry flue gas loss, since they were separately calculated as a wet flue gas loss.

2. Heat loss due to evaporation of water formed due to H_2in fuel (%)

The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to hot water and this carries away heat in the form of its latent heat.

$$L_2 = \frac{9\, x H_2 x\ (584 + C_p\, (T_f - T_a)}{GCV of fuel} \text{ x } 100 \qquad (5.6)$$

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 ℃

T_a = Ambient temperature in ℃

584 = Latent heat corresponding to partial pressure of water vapor

3. Heat loss due to moisture present in fuel (%)

Moisture entering the boiler with the fuel leaves as a superheated vapor. This moisture loss is made up of the sensible heat to bring the moisture to boiling point, the latent heat of evaporation of the moisture, and the superheat required bringing this hot water to the temperature of the exhaust gas. This loss can be calculated with the following formula.

$$L_3 = \frac{M\ x\ \{584 + C_p(T_f - T_a)\}}{GCV of fuel} \text{ x } 100 \qquad (5.7)$$

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

4. Heat loss due to moisture present in air (%)

Vapor in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss. The mass of vapor that air contains can be obtained from psychometric charts and typical values are included below:

$$L_4 = \frac{AAS\ x humidity factor x C_p(T_f - T_a)}{GCV of fuel} \text{ x } 100 \qquad (5.8)$$

Where: AAS = actual mass of air supplied per kg of fuel

Humidity factor = kg of water /kg of dry air

T_a = Ambient temperature in ℃ (dry bulb)

5. Heat loss due to incomplete combustion (%)

Products formed by incomplete combustion could be mixed with oxygen and burned again with a further release of energy. Such products include CO, H_2 and various hydrocarbons and were generally found in the flue gas of the boilers. Carbon monoxide is the only gas whose concentration can be determined conveniently in a boiler plant test.

$$L_5 = \frac{\%\,COxC}{\%\,CO + \%\,CO_2} \text{ x } \frac{5744}{GCVoffuel} \text{ x } 100 \quad (5.9)$$

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 or

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

The other heat losses from a boiler consist of the loss of heat by radiation and convection from the boiler casting into the surrounding boiler house. Energy will be lost from the boiler surface to the wind by convection and radiation energy loss due to the temperature difference between the ambient air and the boiler surface.

The energy loss per unit area of the boiler surface exposed to the ambient temperature was estimated as:

$$L_6 = 0.548 * [(T_s/55.55)^4 - (T_a/55.55)^4] + 1.957 * (T_s - T_a)^{1.25} * \sqrt{[(196.85\,V_m + 68.9)/68.9]} \quad (5.10)$$

5.4.1. Energy performance assessment of Fire tube Boiler- 1

Table: 5.1. Fuel properties and flue gas measured values

	Flue gas measured values	
Fuel properties	Boiler #1	Boiler #2
C : 84.79 %	T_f= 184℃	T_f= 180℃
H_2: wt 12.21 %	T_a= 28℃	T_a = 28℃
S: wt 0.5 %	CO_2= 8.4% by volume	CO_2 = 8.6% by volume
O_2 : 0.5%	O_2 = 9.7% by volume	O_2 = 9.98% by volume
Moisture content: 2%	CO = 7.8% by volume	CO = 15.4% by volume
Specific gravity: 0.8461		
Flash point: 112.3 °F = 44.6℃		
GCV: 43 MJ/kg, NCV:38.46 MJ/kg		

a. The theoretical air required for combustion through (Sachin et.al, 2014) of fire tube boiler -1 is calculated using equation (5.2):

RA = [(11.6 * 84.79) + {34.8 *(12.21 – 0.5/8)} + (4.35 *0.5)]/100

= 14.08 kg of air/kg of fuel

b. Percentage of excess air is determined using equation (5.3):

$$EA = \frac{9.7}{21-9.7} * 100 = 85.84\%$$

c. Actual mass of air supplied/ kg of fuel estimated using equation (5.4) as:

AAS = (1+ 85.84/100) * 14.08

= 26.16 kg/kg of fuel

The various losses associated with the operation of boiler were discussed below (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 (5.5)

$$L_1 = \frac{27.16 * 1.357 \text{kJ/kg k} * (184 - 28)}{43MJ/kg} * 100$$

$$= 13.37\%$$

2. Heat loss due to evaporation of water formed due to H_2 in fuel (%)

The amount of heat loss due to evaporation of water formed due to H_2 in fuel (%) is determined using equation (5.6)

$$L_2 = \frac{9 \, x \, 0.1221 \, x \, (584 + 4.187(184 - 28)}{43MJ/kg} * 100 = 3.16\%$$

3. Heat loss due to moisture present in fuel

It is calculated through equation (5.7)

$$L_3 = \frac{0.02 \, x \, \{584 + 4.187(184 - 28)\}}{43MJ/kg} * 100 = 0.058\%$$

4. Heat loss due to moisture present in air

It is estimated through equation (5.8);

$$L_4 = \frac{26.16 \, x 0.0124 x \, 1.357 kJ/kg \, (184 - 28)}{43MJ/kg} * 100 = 0.16\%$$

5. Heat loss due to incomplete combustion

It is determined through equation (5.9);

$$L_5 = \frac{15.8 \, x 0.8679}{15.8 + 6.4} \text{ x } \frac{5744}{43MJ/kg} \text{ x } 100$$

$$= 0.083\%$$

6. Heat loss due to radiation and convection

This type of loss is estimated through equation (5.10);

i. Heat loss due to radiation and convection from boiler cylinder surface at measured surface temperature of 65℃.

$$L_{cs} = 0.548 * [(338/55.55)^4 - (301/55.55)^4] + 1.957 * (338 - 301)^{1.25} * \sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$$

$= 278.7W/m^2 + 509.6W/m^2$

$= 788.3W/m^2$, where, $A_c = \pi DL = 13.27m^2$

$= 10.46kW$

$$= \frac{10.46kW}{GCV * \dot{m}_{fuel}} * 100 = 1.3\%$$

Where, GCV= 43MJ/kg, $\dot{m}_{fuel} = 0.0188kg/s$

ii. Heat loss due to radiation and convection from boiler front surface at measured surface temperature of 90℃.

$$L_f = 0.548 * [(363/55.55)^4 - (301/55.55)^4] + 1.957 * (363 - 301)^{1.25} * \sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$$

$= 526.84W/m^2 + 971.54W/m^2$

$= 1498.4W/m^2$, $A_f = \frac{\pi D^2}{4} 1.33m^2$

$= 1.99kW$

$$= \frac{1.99kW}{43MJ/kg * 0.0188kg/s} * 100 = 0.25\%$$

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

$$L_b = 0.548 * [(343/55.55)^4 - (301/55.55)^4] + 1.957 * (343 - 301)^{1.25} * \sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$$

$= 324.2W/m^2 + 579W/m^2$

$= 921.3W/m^2$, $A_b = 1.33m^2$

$= 1.225kW$

$$= \frac{1.225kW}{43MJ/kg * 0.0188kg/s} * 100 = 0.152\%$$

L_6 =1.3%+ 0.25%+ 0.152%= 1.7%

Having established the magnitude of all the losses mentioned above, a simple heat balance would give the efficiency of the boiler. The efficiency is the difference between the energy input to the boiler and the heat losses calculated.

$$\eta_{boiler} = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$$

$$= 100 - (13.37 + 3.16 + 0.058 + 0.16 + 0.083 + 1.7)$$

$$= 81.46\%$$

5.4.2. Energy performance assessment of fire tube boiler- 2

a. The theoretical air required for combustion through (Sachin et.al, 2014) of fire tube boiler -1 is calculated using equation (5.2):

RA = [(11.6 * 84.79) + {34.8 *(12.21 – 0.5/8)} + (4.35 *0.5)]/100

= 14.08 kg of air/kg of fuel

b. Percentage of excess air is determined using equation (5.3):

$$= \frac{9.98}{21-9.98} = 90.56\%$$

c. Actual mass of air supplied/ kg of fuel estimated using equation (5.4) as:

AAS = (1+ 90.56/100) * 14.08

= 26.83kg/kg of fuel

The various losses associated with the operation of boiler were discussed below.

1. Heat loss due to dry flue gas

The heat loss due to dry flue gas is calculated using equation (5.5)

$$L_1 = \frac{27.83 * 1.357\text{kJ/kg} * (180 - 28)}{43MJ/kg} * 100$$

$$= 13.35\%$$

2. Heat loss due to evaporation of water formed due to H_2in fuel (%)

The amount of heat loss due to evaporation of water formed due to H_2in fuel (%) is determined using equation (5.6)

$$L_2 = \frac{9\ x\ 0.1221\ x\ (584 + 4.187(180 - 28)}{43MJ/kg} * 100 = 3.12\%$$

3. Heat loss due to moisture present in fuel

It is calculated through equation (5.7)

$$L_3 = \frac{0.02\ x\ (584 + 4.187(\ 180 - 28))}{43MJ/kg} * 100 = 0.03\%$$

4. Heat loss due to moisture present in air

It is estimated through equation (5.8);

$$L_4 = \ = \frac{26.83\ x 0.0124 x\ 1.357\ (180 - 28)}{43MJ/kg} * 100 = 0.48\%$$

5. Heat loss due to incomplete combustion

It is determined through equation (5.9);

$$L_5 = \frac{15.4 x 0.8679}{15.4 + 6.5}\ \text{x}\ \frac{5744}{43MJ/kg}\ \text{x}\ 100$$

$$= 0.08\%$$

6. Heat loss due to radiation and convection

This type of loss is estimated through equation (5.10);

i. Heat loss due to radiation and convection from boiler cylinder surface at measured surface temperature of 60℃.

$$L_{cs} = 0.548*[(333/55.55)^4 - (301/55.55)^4] + 1.957*(333 - 301)^{1.25}$$

$$\sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$$

$$= 235\text{W}/m^2 + 425\text{W}/m^2$$

$$= 660\text{W}/m^2\ ,\ A_c = 13.27m^2$$

$$= 8.758\text{kW}$$

$$= \frac{8.758\text{kW}}{43MJ*0.012kg/s} * 100 = 1.7\%$$

ii. Heat loss due to radiation and convection from boiler front surface at measured surface temperature of 97℃.

$$L_f = 0.548 * [(370/55.55)^4 - (301/55.55)^4] + 1.957 * (370 - 301)^{1.25} *$$

$$\sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$$

$$= 606.2\text{W}/m^2 + 1110.5\text{W}/m^2$$

$$= 1716.7\text{W}/m^2\ ,\ A_f = 1.33m^2$$

$$= 2.28\text{kW}$$

$= \frac{2.28kW}{43MJ*0.012kg/s} * 100 = 0.44\%$

iii. Heat loss due to radiation and convection from boiler front surface at measured surface temperature of 73℃

L_b = $0.548 * [(346/55.55)^4 - (301/55.55)^4] + 1.957 * (346 - 301)^{1.25} * \sqrt{[(196.85 * 2.5 + 68.9)/68.9]}$

= 352.4W/m^2+ 650.8W/m^2

= 1003.3W/m^2, A_b = 1.33m^2

= 1.33kW

$= \frac{1.33kW}{43MJ*0.012kg/s} * 100 = 0.26\%$

L_6 = 1.7%+ 0.44%+0.26% =2.4%

Having established the magnitude of all the losses mentioned above, a simple heat balance would give the efficiency of the boiler. The efficiency is the difference between the energy input to the boiler and the heat losses calculated.

$\eta_{boiler} = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6)$

= 100 – (13.35+ 3.12+ 0.03+ 0.48+ 0.08+ 2.4)

= 80.54%

5.5. Hot water distribution demand to the dryers

Estimating the total hot water production is needed to analyze the useful energy observed by hot water for drying pasta. In this study the hot water distribution and demand to the dryer was determined. The hot water generated by two different boilers (i.e. boiler -1 and boiler -2) was supplied to the dryers. Boiler -1 feeds the hot water for dryer-2 and dryer -3. It is observed that about 41.6% at average is supplied to dryer -2 and about 58.4% is to dryer -3 of 658.6 kW.

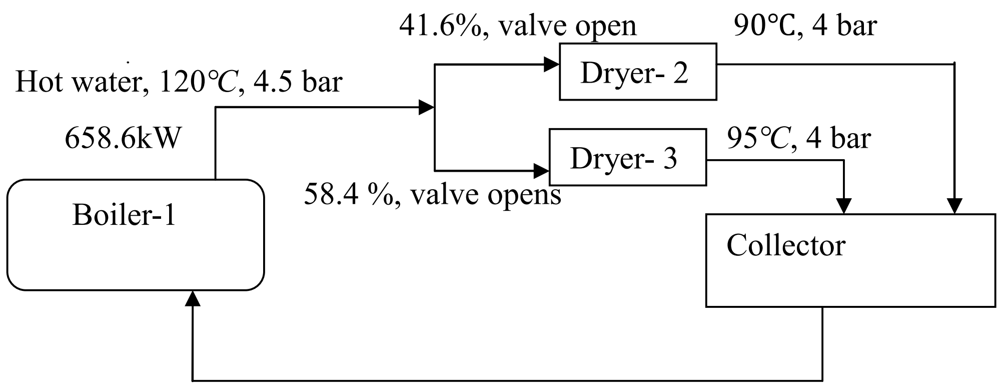


Figure: 5.3. Hot water distribution from boiler-1

The second boiler feeds hot water to dryer- 4 of plant production- 4.

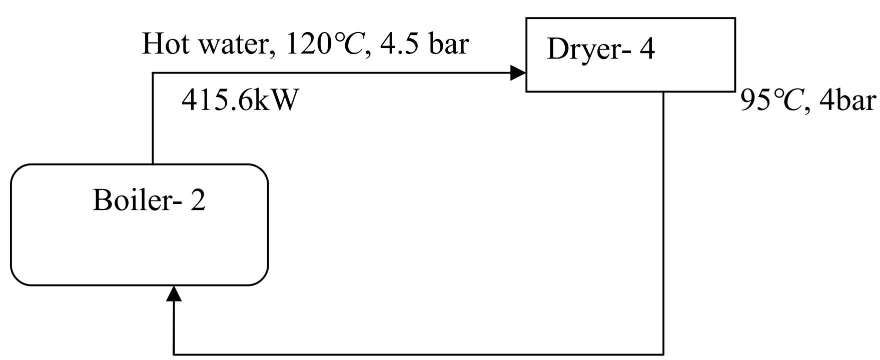


Figure: 5.4. Hot water distribution from boiler-2

CHAPTER 6

Mass and Energy Balance Analysis in the production Processes

6.1. Introduction to mass and energy balance

Material and energy balances are very important in a pasta production plant. Material balances are fundamental to the control of processing, particularly in the control of yields of the products. As the pasta and macaroni travels from dryer unit to the next, heat and mass are transferred during this process. By imagining a control volume and establishing mass and energy balance equations is significant. Solving the equations would give the evaporation rate and the change in the moisture contents.

The energy equation for a fixed control volume is given by:

$$\dot{Q} - \dot{W}s - \dot{W}ss = \frac{\partial}{\partial t}\left[\int \left(u + \frac{1}{2}V^2 + gz\right)\rho d\gamma\right] + \int \left(H + \frac{1}{2}V^2 + gz\right)\rho(v.n)dA] \qquad (6.1)$$

Where; $\dot{Q}$ - is heat added to the system, $\dot{W}s$ - is the shaft work, $\dot{W}ss$ - is shear work

Assumptions:

i. The system doesn't do any work, ($\dot{W}s$ = 0, $\dot{W}ss$ =0).

ii. Steady state condition is assumed.

iii. The potential and kinetic energies are neglected.

The above equation (6.1) is simplified to:

$$\dot{Q} = \int H\, \rho(v.n)dA \qquad (6.2)$$

Equation (6.2) indicates that the heat added to the system is equal to heat energy out from the system.

Mass balance of the control volume becomes:

$$\frac{dm}{dt_{in}} - \frac{dm}{dt_{out}} = 0 \qquad (6.3)$$

6.2. Mass and moisture balance

6.2.1. Mass balance

According to the concept of control volume mass balance, the flour which enters in to the system is equal to the sum of dried pasta which is leaving the system and the collected scrap pasta out of the dryer. The mass balance of the pasta and macaroni production process of different plant line (i.e.2, 3 and 4) of the factory is summarized in table 6.1:

Table: 6.1. The factory plant capacity

Parameter	Capacity of Plant -2 kg/hr	Capacity of plant-3 kg/hr	Capacity of Plant-4 kg/hr
Mass flow rate of flour	1000	1500	1400
Mass flow rate of pasta	924	1395	1365

There were over dried pasta due to power interruption which has average moisture of 10% called scrap pasta. It was estimated as the difference between mass of flour and the output normal pasta.

a. Mass balance of 1000 kg/hr of flour for long pasta production process plant line -2

$$\dot{m}_{f\ in} = \dot{m}_{pasta\ out} + \dot{m}_{scrap\ out} \quad (6.4)$$

1000 kg/hr = 924 kg/hr +$\dot{m}_{scrap\ out}$

$\dot{m}_{scrap\ out}$ = 76 kg/hr

b. Mass balance of 1500 kg/hr of flour for long pasta production process plant line-3

$$\dot{m}_{in} = \dot{m}_{pasta\ out} + \dot{m}_{scrap\ out} \quad (6.5)$$

1500 kg/hr = 1395 kg/hr +$\dot{m}_{scrap\ out}$

$\dot{m}_{scrap\ out}$ = 105 kg/hr

c. Mass balance of 1400kg/hr of flour for short Macaroni production process plant line-4

$$\dot{m}_{f\ in} = \dot{m}_{pasta\ out} + \dot{m}_{scrap\ out} \quad (6.6)$$

1400kg/hr = 1365kg/hr +$\dot{m}_{scrap\ out}$

$\dot{m}_{scrap\ out}$ = 35kg/hr

6.2.2. Moisture Balance

Moisture balance starts from the flour which has 14% moisture and the water which was equal to 30% of the flour mass is added during dough formation. The following table approves the amount of solid and wet mass of flour and pasta at different plant lines.

Table: 6.2. Measured wet and solid mass of flour and pasta in the factory

	Plant line-2		Plant line-3		Plant line-4	
	Wet mass kg	Solid mass kg	Wet mass kg	Solid mass kg	Wet mass kg	Solid mass kg
Flour	1000	860	1500	1290	1400	1204
pasta	1300	860	1950	1290	1820	1204

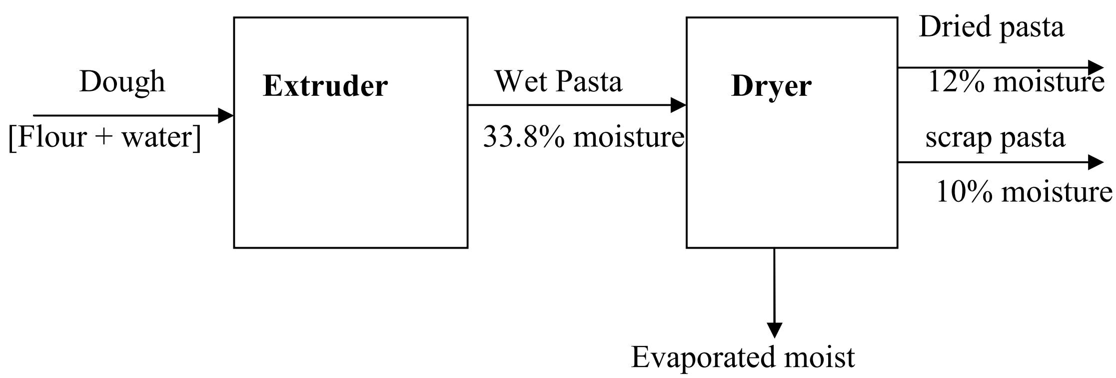


Figure: 6.1. Diagram of mass and moisture balance

Dryer is an assembly of equipments used for removal of moisture from solids by evaporation. The dryer dries the pasta to the correct moisture level. The moisture balance is basically used for to estimate the amount moisture evaporated as a result of thermal energy input to the dryer.

The amount of moisture evaporated from the pasta at different plant lines was estimated in this study as follow:

i. Moisture balance of 1000 kg of flour for long pasta production process plant line-2

$$m_{f\ in} * H_{in} = m_{out} * H_{out} + m_{out} * H_{scrap} + \text{E} \quad (6.7)$$

1300 kg * 0.338 = 1000 kg * 0.12 + 76 kg*0.1 + E

E = 311.8 kg of moisture evaporated

ii. Moisture balance of 1500 kg of flour for long pasta production process plant line- 3

$$m_{in} * H_{in} = m_{out} * H_{out} + m_{out} * H_{scrap} + E \quad (6.8)$$

1950 kg * 0.338 = 1500 kg * 0.12 + 156 kg*0.1 + E

E = 463.5 kg of moisture evaporated

iii. Moisture balance of 1400 kg of flour for short pasta production process plant line- 4

$$m_{in} * H_{in} = m_{out} * H_{out} + m_{out} * H_{scrap} + E \quad (6.9)$$

1820 kg * 0.338 = 1400 kg * 0.12 + 35 kg*0.1 + E

E = 443.66 kg of moisture evaporated

6.3. Dryer performance analysis

The electrical and thermal energy consumptions were evaluated considering the real medium powers and working times. Drying is the process responsible of the most energy consumption; an energy balance was carried out in order to determine energy losses and to determine the thermal efficiency of the dryer.

Drying is a process that requires high-energy input because of the high latent heat of water evaporation and relatively low energy efficiency of industrial dryers. It is reported that industrial dryers consume about 12% of the total energy used in manufacturing processes and the drying cost may rise to 60-70% of the total cost (Ahmed et.al., 2018).

The heat input to a dryer can be derived from the quantity of fuel consumption stoichiometric and excess air input for combustion and combustion thermal efficiency. The thermal energy input to the dryer, hot water input from quantity of fuel fired and dryer efficiency as well as the total heat input was estimated with heat balance.

An efficient dryer is a dryer that maximizes the use of the sensible heat present in the drying air to evaporate the water from the product. Ideally, the outlet air should be saturated with moisture and its temperature is as low as possible. A common indicator used to characterize the performance of a dryer is its specific energy consumption, defined as the energy required to evaporate 1 kg of water from the product.

In drying process the moisture is removed from the pasta specifically by evaporation. To achieve drying, the latent heat of evaporation must be supplied to turn each kilogram of moisture into vapor. The heat required in the dryer is generally made up of the following:

- Sensible heat to for raising the pasta to the drying temperature.
- Heat required to evaporate moisture from pasta

According to First law of thermodynamics concept heat added to the system is equal to heat energy out from the system where there is no work done, kinetic and potential energies are neglected and steady state condition is assumed.

$$Q_{in,dryer} = Q_{sensible} + Q_{latent} + Q_{condensate\ return} + Q_{loss} \qquad (6.10)$$

The dryer efficiency can be determined the ratio of total heat consumed due to latent heat of vaporization, sensible heat which raise the pasta temperature from 50℃ to average temperature of 75.84℃ and the condensate heat from the dryer to the heat input to the dryer.

i. Heat given to dried pasta (heat in the product)

$$Q_s = \dot{m}_{out\ x} C_{ps}\ [T_{s\ out} - T_{s\ in}] + \dot{m}_{scrap}\ x\ C_{ps}\ [T_{scrap} - T_{s-in}] \qquad (6.11)$$

ii. Heat for vaporization of liquid

$$Q_{lv} = \dot{m}_{out}\, [H_{in} - H_{out}]h_{fg} + \dot{m}_{scrap}\ [H_{in} - H_{out,scrap}]h_{fg} \qquad (6.12)$$

iii. Condensate heat

$$Q_{con} = \dot{m} * C_p*(T_{out} - T_{fw}) \qquad (6.13)$$

iv. The dryer thermal efficiency

$$\eta_{dryer} = \{\frac{Q_{latent} + Q_{sensible} + Q_{con}}{Q_{in}}\}*100 \qquad (6.14)$$

Thus the absolute minimum amount of heat which must be supplied for a drying process of different pasta plant line was discussed below.

6.3.1. Dryer performance analysis of plant line-2

Most of the following parameters are measured to conduct the dryer performance analysis of plant-2.

Table: 6.3.Parameters needed for plant-2 dryer performance analysis

No.	Measured parameters	Measured values
1	Amount of pasta produced ($\dot{m}_{out}$)	924 kg/hr
2	Amount of scrap pasta ($\dot{m}_{scrap}$)	76 kg/hr
3	Pasta moisture at inlet (H_{in})	0.338 kg/kg of pasta
4	pasta moisture at final product(H_{out})	0.12 kg/kg of pasta
6	Temperature of pasta at inlet ((T_{s-in})	50 °C
7	Temperature of pasta at final product (T_{s-out})	75.84 °C/wb 53°C
8	Temperature of scrap pasta in the collector(T_{s-dust})	85°C
9	Specific heat of pasta(C_{P-s})	1.8 kJ/kg k
10	Specific heat liquid (C_{P-l})	4.19 kJ/kg°C
11	Latent heat of evaporation (h_{fg})	2257 kJ/kg

i. Sensible heat needed to raise the temperature of pasta from 50°C to the average surface temperature of pasta in the dryer i.e. 75.84°C.

The value of$C_P$pastais checked through the Heldman and Singh formula (Brunetti et.al, 2015).

$C_{P\ pasta}$ = ($1.424x_c + 1.549x_p + 0.675x_f + 0.837x_a + 4.187x_w$) kJ/kg k

From Africa plc wheat test analysis,

x_c = 69.67%,is the carbohydrate fraction; x_a= 0.00%, is the ash fraction;

x_p= 13.37%, is the protein fraction; x_w= 14.28%, is the water fraction

x_f= 0.00%, is the fats fraction;

Sensible heat needed is estimated using equation (6.7);

Q_s = 0.256 kg/s * 1.8kJ/kg k [75.84 – 50] + 0.021 kg/s * 1.81.8kJ/kg k [85 – 50]

= 13.23kW

ii. Heat for vaporization of liquid will be determined through equation (6.8) which results:

Q_{lv}= 0.256 kg/s * [0.338 - 0.12] * 2257 kJ/kg + 0.021 kg/s * [0.338 – 0.10] * 2257 kJ/kg
= 137.2 kW

iii. Condensate heat

The condensate heat was estimated in reference to 20℃ of feed water. Since automatic valve controls the amount of hot water demand to the dryer which were at the average of 41.6% opened, the heat energy input to dryer-2 was estimated at about 41.6% of 658.6 kW heat energy from water boiler was equal to 274 kW. Using equation (6.9) the condensate heat is estimated as:

$$Q_{con} = 0.19 \text{ kg/s} * 4.187 \text{ kJ/kg k} * (90℃ - 20℃)$$
$$= 55.68 \text{ kW}$$

The dryer thermal efficiency of production plant 2 will be estimated through equation (6.14) as:

$$\eta_{dryer\ 2} = \frac{13.23kW + 137.2kW + 55.68kW}{274kW} * 100 = 75.2\%$$

6.3.2. Dryer performance analysis of plant line-3

Most of the following parameters are measured to conduct the dryer performance analysis of plant-3.

Table: 6.4. Parameters needed for plant-3 dryer performance analysis

No.	Measured parameters	Measured values
1	Amount of pasta produced ($\dot{m}_{out}$)	1395 kg/hr
2	Amount of scrap pasta ($\dot{m}_{scrap}$)	105kg/hr
3	Pasta moisture at inlet (H_{in})	0.338 kg/kg of pasta
4	pasta moisture at final product(H_{out})	0.12 kg/kg of pasta
6	Temperature of pasta at inlet ((T_{s-in})	50 ℃
7	Temperature of pasta at final product (T_{s-out})	75.84 ℃/wb 53℃
8	Temperature of scrap pasta in the collector($T_{s-scrap}$)	85℃
9	Specific heat of pasta(C_{P-s})	1.8 kJ/kg k
10	Specific heat liquid (C_{P-l})	4.19 kJ/kg℃
11	Latent heat of evaporation ((h_{fg})	2257 kJ/kg

i. Sensible heat needed to raise the temperature of pasta from 50°C to the average surface temperature of pasta in the dryer i.e. 75.84°C.

Sensible heat needed is estimated using equation (6.7)

Q_s = 0.3875 kg/s * 1.8kJ/kg k [75.84 – 50] + 0.0292 kg/s * 1.8kJ/kg k [85 – 50]
= 19.22kW

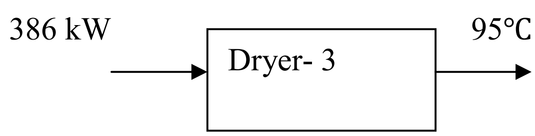
ii. Heat for vaporization of liquid will be determined through equation (6.8) which results:

Q_{lv}= 0.3875kg/s * [0.338 - 0.12] * 2257 kJ/kg + 0.0292 kg/s * [0.338 – 0.10] * 2257 kJ/kg
= 206kW

iii. Condensate heat

The condensate heat was estimated in reference to 20℃ of feed water. Since automatic valve controls the amount of hot water demand to the dryer which were at the average of 58.4% opened, the heat energy input to dryer-3 was estimated at about 58.4% of 658.6 k heat energy from water boiler was equal to 386 kW.

Using equation (6.9) the condensate heat is estimated as:



$$Q_{con} = 0.266 \text{ kg/s} * 4.187 \text{ kJ/kg k} * (95℃ - 20℃) = 83.5\text{kW}$$

The dryer thermal efficiency of production plant-3 will be estimated through equation (6.10) as:

$$\eta_{dryer\ 3} = \frac{19.22\text{ kW} + 206\text{ kW} + 83.5\text{ kW}}{386\text{ kW}} * 100 = 80\%$$

6.3.3. Dryer performance analysis of plant line-4

Most of the following parameters are measured to conduct the dryer performance analysis of plant-4.

Table: 6.5. Parameters needed for plant-4 dryer performance analysis

No.	Measured parameters	Measured values
1	Amount of pasta produced (w_{out})	1365 kg/hr
2	Amount of scrap pasta (w_{dust})	35 kg/hr
3	Pasta moisture at inlet (m_{in})	0.338 kg/kg of pasta
4	pasta moisture at final product (m_{out})	0.12 kg/kg of pasta
6	Temperature of pasta at inlet ((T_{s-in})	50 ℃
7	Temperature of pasta at final product (T_{s-out})	75.84 ℃/wb 53℃
8	Temperature of scrap pasta in the collector (T_{sscrap})	85 ℃
9	Specific heat of pasta(C_{P-s})	1.8 kJ/kg k
10	Specific heat liquid (C_{P-l})	4.19 kJ/kg℃
11	Latent heat of evaporation ((h_{fg})	2257 kJ/kg

i. Sensible heat needed to raise the temperature of pasta from 50°C to the average surface temperature of pasta in the dryer i.e. 75.84°C.

Sensible heat needed is estimated using equation (6.7);

Q_s = 0.379 kg/s * 1.8kJ/kg k [75.84 – 50] + 0.0097 kg/s * 1.8kJ/kg k [85 – 50]

= 18.24kW

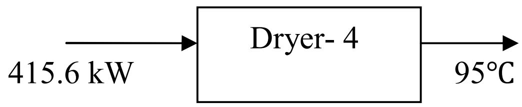
ii. Heat for vaporization of liquid will be determined through equation (6.8) which results:

Q_{lv} = 0.379 kg/s *[0.338 - 0.12] * 2257 kJ/kg + 0.0097 kg/s * [0.338 – 0.10] * 2257 kJ/kg

= 191.34 kW

iii. Condensate heat

The condensate heat was estimated in reference to 20℃ of feed water. The heat energy input to dryer-4 was estimated to be 415.6kW.



Using equation (6.9) the condensate heat is estimated as:

$$Q_{con} = 0.30\ kg/s * 4.19 kJ/kg\ k * (95℃ - 20℃)$$

$$= 94.3kW$$

The dryer thermal efficiency of production plant-4 will be estimated through equation (6.10) as:

$$\eta_{dryer\ 4} = \frac{191.34kW + 18.24kW + 94.3kW}{415.6kW} * 100 = 73.1\%$$

The total an uncounted heat loss the dryers is the sum of heat loss in different production line plant lines.

$$Q_{total\ loss} = Q_{loss\ 2} + Q_{loss\ 3} + Q_{loss\ 4}$$

$$= 67.95\ kW + 77.2\ kW + 111.8\ kW$$

$$= 256.95\ kW$$

After this an in-depth thermal energy analysis which was carried out focusing on dryer part of production process plant, it was observed that 2,250,899.52 kWh thermal energy lost annually and the dryer thermal efficiency was observed 75.2%, 80%, 73.1% of different pasta and macaroni plants dryer of 2, 3, and 4, respectively. And also the total annual thermal energy consumption was the summation of latent, sensible heat energy and the total annual heat loss from the dryer.

$$ATEC_{dryer-2} = [Q_{loss} + Q_{latent\ heat} + Q_{sensible\ heat}] * h_y$$

$$= (67.95\ kW + 137.2\ kW + 13.23\ kW)*24*365$$

$$= 1,913,008.8\ kWh$$

$$ATEC_{dryer-3} = [Q_{loss} + Q_{latent\ heat} + Q_{sensible\ heat}] * h_y$$

$$= (77.2\ kW + 206\ kW + 19.22\ kW)*24*365$$

$$= 2,649,199.2\ kWh$$

$$ATEC_{dryer-4} = [Q_{loss} + Q_{latent\ heat} + Q_{sensible\ heat}] * h_y$$

$$= (111.8\ kW + 191.34\ kW + 18.24\ kW)*24*365$$

$$= 2,815,288.8\ kWh$$

CHAPTER 7

Energy Analysis of Electrical Machines and Lighting systems

7.1. Analysis of electrical motor

Industrial motors account for a major part of total industrial energy use. The amount of energy used by a motor-driven system is directly proportional to the power required by the system times the period of time it is operating. Since power is expressed in kilowatts and time in hours, the conventional unit of energy is kilowatt-hours [kWh]. Power and energy measurements are used to determine loads on equipment, energy consumption, operating costs, and to verify proper system sizing and operation. Power is proportional to the product of circuit voltage (V), amperage or current (I), and power factor (PF). For a three-phase system.

Percentage loading [% L] $=\frac{V_m * I_m}{V_r * I_r} * 100$ (7.1)

Power input $[P_{in}] = \sqrt{3} * V_m * I_m *$ p.f (7.2)

Where $V_m = 380V, V_r$=400 V

Motor efficiency is the ratio of a motor's useful mechanical power output to its total electrical power input. Motors convert electrical energy to mechanical energy.

$\eta_{motor} = \frac{\text{Rated power}}{\text{power input}} *$ load (7.3)

Motor losses are the difference between the motor input and output power.

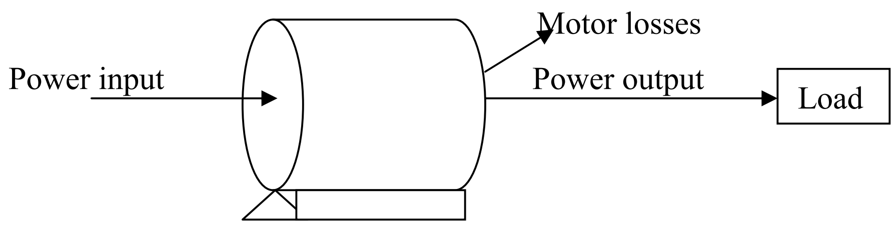


Figure: 7.1.Electrical motor

Annual energy consumption for electrical motors of boiler is estimated by using the following equation:

$$AEC = P_{in\ total} * L * h_y \qquad (7.4)$$

7.2. Investigation of machine driving electrical motors

Machine driving motors are the motors that have different function in machines that are used to process the input raw material to the end product output. In this study it was observed that there were different motors with different rated power capacities and also there were motors with similar rated power capacities and rated current. The current and power factor were measured and the power input, loading and efficiency of motors were estimated by using equation (7.1), (7.2) and (7.4). It was summarized in the table 7.1.

Table: 7.1. Rated and measured values of machine driving electrical motors

P_r $[kW]$	Qty	$I_r[A]$	$I_m[A]$	Pf	%L	$P_{in}[kW]$	η
0.2	2	0.57	0.41	0.80	68.3	0.4	0.63
0.25	11	0.72	0.34	0.76	44.9	1.9	0.66
0.5	2	0.92	0.72	0.88	74.3	0.8	0.89
0.55	28	1.5	0.89	0.78	56.4	12.8	0.68
0.75	94	2.1	1.3	0.76	58.8	61.1	0.68
1.1	30	2.6	1.8	0.80	65.8	28.4	0.76
1.5	64	3.3	2.5	0.80	72.0	84.2	0.82
2.8	27	6.1	4.48	0.82	69.8	65.3	0.81
3	1	7.6	5.56	0.84	69.5	3.1	0.68
3.5	4	8.2	6.86	0.84	79.5	15.2	0.73
6.5	1	14.65	12.5	0.83	64.8	5.5	0.77
7.5	1	19	15.56	0.76	77.8	6.0	0.75
20	6	50	36	0.80	68.4	113.7	0.72

7.2.1. Annual energy consumption of driving electrical motors

In this section of study, annual energy consumption for normal motors of product processing machine of plant lines with their respective production process zones were estimated by using the following equation:

$$AEC = P_{in} * L * h_y \tag{7.5}$$

Where, AEC is Annual energy consumption for normal motor (kWh); and L Percentage loading. The electric motor energy consumption machine drives during pasta production process of plant 2 and 3 with respective production process zones.

Table: 7.2. Annual electrical energy consumption of plant-2 and -3

Production process zone	Qty	$P_r[kW]$	AEC $[kWh]$	Qty	$P_r[kW]$	AEC $[kWh]$
Inlet - pre dryer	4	20	1917389	2	0.2	4786
[3386010kWh]	2	7.5	204458	2	2.8	340589
	8	0.55	173911	4	3	147588
	6	0.75	139074	2	3.5	68482
Pre dryer Zone	20	1.5	3784320	4	2.8	273929
[7126139 kWh]	21	1.1	2796155	10	0.55	271735
Dryer Zone	81	0.75	25346193	1	2.8	17121
[25374183kWh]	2	0.55	10869			
Cooling Zone	6	0.75	139074	4	0.55	43478
[544865kWh]	8	1.1	405791			
Cooler- packaging	2	0.75	15453	6	0.25	35399
[368258kWh]	4	2.8	273929			

The electric motor energy consumption machine drives during macaroni production process of plant-4 with respective production process zones.

Table: 7.3. Annual electrical energy consumption of plant-4

Production process zone	Qty	$P_r[kW]$	AEC $[kWh]$	Qty	$P_r[kW]$	AEC $[kWh]$
From inlet – dryer [1341960kWh]	2	20	454181	1	6.5	31221
	1	7.5	40892	1	2.8	14797
	3	0.55	20454	2	3	75494
	1	0.75	3348	5	3.5	661599
	1	0.2	1197	1	1.1	454181
	2	1.5	33302			
Dryer zone [5324488kWh]	1	0.75	3348	1	2.8	14797
	2	0.5	10414	5	0.55	56817
	5	0.25	16716	1	3	18955
	25	1.5	5203440			
From cooling - packaging. [99081kWh]	2	0.25	2675	6	0.55	81817
	1	0.2	1192	2	0.75	3392

The detailed annual electrical energy consumption of 199 electrical motors was conducted for production plants of 2 and 3 with their respective production zones. In general, 3386 MWh is consumed by machine driving motors from inlet to pre dryer, 7126 MWh was consumed by pre dryer driving motors, 25374 MWh was consumed by the dryer, 545 MWh was consumed by cooling zone and 368 MWh was consumed by the driving motors from cooling to packaging of the total annual electrical energy consumption of 36799 MWh.

7.3. Performance evaluation of pumps with motors

All pumps are centrifugal, which have the designed capacities of 3 to 84 m^3/hr volume flow rate and 7 to 21 m head. In order to analyze energy performance of the pumps with their motors data must be collected from nameplate and measurements.

7.3.1. Boiler and utility pump motor rated and measured values

In thermal power plant, boiler feed pump is equivalent to the heart of the plant. The hot water is produced by feeding the makeup water to the boiler by feed pump and it is also feed to the dryer by the pump. This means unexpected stop of boiler feed pump completely stops the thermal power generation. Using equation (7.1), (7.2) and (7.3) the power input, loading and motor efficiency is summarized in table 7.7.

Table: 7.4. Boiler pump motor rated and measured values

Motor number	Rated power	Rated current	I_m[A]	pf	P_{in}[kW]	Loading	$\%\eta_{motor}$
M-81-HE	2.2	4.2	3.60	0.86	2.04	0.81	87.91
M-82-HE	2.2	4.2	3.60	0.86	2.04	0.81	87.91
M-81A	5.5	11.5	10.45	0.76	5.22	0.64	67.40
M-82A	5.5	11.5	9.60	0.80	5.05	0.79	86.00
M-81- C_{pump}	5.5	11.5	10.45	0.74	5.08	0.64	69.30
M-82- C_{pump}	5.5	11.5	9.60	0.78	4.93	0.79	88.10
					$\sum P_{in}$ =24.4kW	**Av = 75%**	**Av = 81.1%**

Using equation (7.5), the annual energy consumption was estimated as:

AEC= 24.4kW * 0.75* 8760 hr

= 160308kWh

Annual electrical energy loss can be estimated from motor efficiency as:

AEL = 160308kWh*0.19

= 30458.5kWh

7.3.1.1. Analysis of boiler, utility and chiller pump efficiency

Power gained by the hot water and condensate return

$$p_{out} = \rho\, Q g\, \Delta H \qquad (7.6)$$

Where; ρ - fluid density, Q - fluid flow rate, g- acceleration due to gravity and ΔH – head pump

The mechanical power of the motor can be calculated by equation (7.7).

$$P_{mec} = \frac{P_{elec,in}}{\eta_m} \qquad (7.7)$$

The efficiency of pump is given by Equation

$$\eta_p = \frac{p_{out}}{P_{mec}} \qquad (7.8)$$

Using equation (7.6), (7.7) and (7.8) the mechanical power, fluid power and pump efficiency was summarized in the following table.

Table: 7.5. Summary of boiler pump analysis

Motor number	Measured parameters			Calculated parameters		
	ΔH [m]	$\dot{Q}[m^3/s]$	$\rho[kg/m^3]$	p_{mec}[kW]	p_{out}[kW]	η_p
M-81-HE	6	0.002	998	2.32	0.12	5.2%
M-82-HE	6	0.002	998	2.32	0.12	5.2%
M-81A	9	0.017	943.4	7.74	1.41	18.2%
M-82A	9	0.01	943.4	5.87	0.83	14.1%
M-81- C_{pump}	9	0.0166	958	7.33	1.4	19.1%
M-82- C_{pump}	9	0.01	958	5.60	0.85	15.2%

There are 10 centrifugal pumps that are serving the utility department rated and measure values are summarized in the following table.

Table: 7.6. Rated and measured values of utility pumps

Motor	Quantity	Motor[kW]	I_r [A]	I_m[A]	L	pf	p_{in}[kW]	η_m
Utility pump	10	2.2kW	4.2	3.15	0.71	0.86	17.8	0.87

Annual energy consumption for utility pump is estimated by using equation (7.5).

AEC = 17.8kW * 0.71* 8760 hr

= 110709kWh

It was also estimated annual electrical energy loss can be estimated from motor efficiency as:

AEL =110709kWh*0.13

= 14392.2kWh

Using equation (7.6), (7.7) and (7.8) the mechanical power, fluid power and pump efficiency was summarized in the following table.

Table: 7.7. Summary of utility pump analysis

Motor	Measured parameters			Calculated parameters		
	ΔH [m]	$\dot{Q}[m^3/s]$	$\rho[kg/m^3]$	p_{mec}[kW]	p_{out}[kW]	η_p
Utility pump	6	0.009	1000	20.5	5.3	0.25

There are 4 centrifugal Pump motors of chillers. The rated and measured values were stated in the following table.

Table: 7.8. Rated and measured values of chiller pumps

	Motor No.	Rated power	Rated current	I_m	p.f	L	P_{in}[kW]	η_{motor}
Chiller 1	M-92 3p	2.2	4.2	3.56	0.85	0.86	2.13	0.89
	M-94 3p	1.9	3.8	3.24	0.83	0.81	1.77	0.87
Chiller 2	M-92 1p	1.39	2.8	2.34	0.84	0.79	1.29	0.85
	M-94 3p	0.82	1.6	1.32	0.86	0.78	0.75	0.86
						Av. 81%	$\sum P_{in}$ **=5.94kW**	**Av = 87%**

Annual energy consumption for pump motors of chillers is estimated by using equation (7.5)

AEC = $P_{in\ total}$* L * h_y

= 5.94 kW * 0.81* 8760 hr

= 42148 kWh

Annual electrical energy loss due to inefficient motors of pump motors of chillers is estimated as:

AEL = 42148 kWh * 0.13

= 5479.3 kWh

7.4. Investigation of lighting systems

Lighting load is where most of the energy is wasted than consumed. Several places were identified during the audit, as the place for easy and efficient energy savings. A count on lighting and calculation of the light energy consumed were done.

Florescent tubes

The energy consumption of 60 W tubes light will be:

- Total number of tube lights being 72,
  Total energy consumed by the tube lights is 72*60*24*365 = 37843200kWh
- Energy consumed per year will be 136 GJ/year.

CHAPTER 8

Energy Analysis of Utility system

8.1. Performance Evaluation of Air Compressor with Motor

One of the major electrical energy utilizing equipment of the factory is air compressor with its motor. In order to analyze energy performance of the air compressor with its motors data must be collected from nameplate and measurements.

8.1.1. Performance evaluation of air compressor motor

The air compressors motor which was used in the industry was studied, and a detailed analysis is done to identify the energy saving potential. The power input, loading and motor efficiency of the air compressor and the power consumption during loading and unloading were calculated. The time taken for loading and unloading was also noted.

Table: 8.1. Rated and measured values of air compressors

	Rated power	Rated Current I_r	Loaded I_m	Unloaded I_m	pf
Air compressor-1	5.6 kW	15A	10A	0.25A	0.82
Air compressor-2	11.2kW	28A	19.5A	0.25A	0.81

Parameters that are needed to audit the performance of compressor are power input, percentage of loading, power factor, mechanical and fluid power. Using equation (7.1) and (7.2) the Percentage loading [% L] and power input were determined as:

$\% L_{comp\ 1}$= 1.6% unloaded, 66.67% loaded

$\% L_{comp2}$= 0.89% unloaded, 69.6% loaded

$P_{in\ comp\ 1}$ = 0.135 kW unloaded, 5.4 kW [loaded]

$P_{in\ comp\ 2}$= 0.133 kW unloaded, 10.4 kW [loaded]

The air compressor motor efficiency was determined using equation (7.3).

$$\eta_{m\ 1} = \frac{5.6\text{kW}}{5.4\text{kW}} * 66.67\% = 69.1\%, \quad \eta_{m\ 2} = \frac{11.2\text{kW}}{10.4\text{kW}} * 69.6\% = 75\%$$

8.1.2. Air compressor performance evaluation

The capacity, mechanical power of its motor, fluid power input and efficiency of the air compressor were determined in this study.

The mechanical power of the motor is calculated by Equation

$$P_{mec}=\frac{P_{elec,in}}{\eta_m} \quad (8.1)$$

$$P_{mec\,1}=\frac{5.4\text{ kW}}{0.691}=7.8\text{ kW},\ P_{mec\,2}=\frac{10.4\text{ kW}}{0.75}=13.87\text{ kW}$$

The mass flow rate of air deliver to the pressure vessel is given by equation

$$\dot{m}_{air}=\frac{(P_{2-}\,P_1)*V_{vessel}}{R*\,T_1*T_{time}} \quad (8.2)$$

$$=\frac{900kpa\,*2\,m^3}{0.287*301*180}=0.103\text{kg/s}$$

Where; $\dot{m}_{air}$-mass flow of air, $(P_{2-}\,P_1)$ – pressure difference, V_{vessel} - compressed air storage,R -universal gas constant, T_1-inlet air temperature,T_{time}- time taken to rise the pressure(P_2)

Compressed air temperature

$$T_2=T_1\,*[\frac{P_2}{P_1}]^{\frac{k-1}{n*k}} \quad (8.3)$$

= 301k *1.29= 387.85k, where; k- polytrophic index (1.3)

The power gained by the air is given

$$P_{out}=\dot{m}_{air}*\,C_p(T_2-T_1) \quad (8.4)$$

= 0.103kg/s * 1.005kJ/kg k *(387.85k – 301k)

= 8.99kW

Where,P_{out} - power gained by air, C_p - specific heat capacity of air

Compressor efficiency is given by

$$\eta_C=\frac{P_{out}}{P_{mec}}*100 \quad (8.5)$$

$$=\frac{8.99\text{ kW}}{21.67\text{ kW}}*100=41.5\%$$

Overall compressor efficiency is given by

$$\eta_{overall} = \frac{P_{out}}{P_{elec\,in}} * 100 \quad (8.6)$$

$$= \frac{8.99\ \text{kW}}{16.1\text{kW}} * 100 = 55.8\%$$

The air compressor annual energy consumption was determined using (Saidur et.al., 2010)equation was determined as:

$$\text{AEC} = \sum[\,(P_L * T_L) + (P_{UL} * T_{UL})] * h_y \quad (8.7)$$

= [15.8 kW*0.72 hr + 0.268 kW * 0.278]*8760 hr, T_L = 2600sec, T_{UL} = 1000sec

= 100306.4kWh

Where, AEC- Annual energy consumption; P_L- Power consumed during loading [kWh]; P_{UL}- Power consumed during unloading [kWh]; T_L- Compressor loading time [sec] and T_{UL} - Compressor unloading time [sec].

8.2. Investigation of water chillers'

In food manufacturing plants, chilled water systems are used for cooling process. The key components of a chilled water system are chillers, chilled water pumps and condenser water pumps. A chilled fluid, which is normally water at low temperature systems is cooled by a chiller and distributed to various loads using chilled water pumps. Once the chilled fluid absorbs heat from the load, it is then circulated back to the chiller.

The heat absorbed by the chiller is rejected to the environment through the condenser which can be water-cooled or air-cooled. In water-cooled chilled water systems, water from cooling towers is pumped to the condenser to remove heat using condenser water pumps. It is observed that the factory is using air cooled type water chiller. The energy consumption in a chiller is mainly by the compressor motor and air supplying fan.

8.2.1. Electrical power input to compressors and condenser fan of the chiller-1

The total rated power input to the chiller was 102 kW; of this 84 kW was that of chiller compressor and the left 18 kW was that of condenser fan under full load.

The compressor and condenser fans current were noted on r, s and t wires using a clamp-meter. Using equation (7.1), (7.2) and (7.3) the power input, loading and motor efficiency is summarized in table 8.2.

Table: 8.2. Rated and measured values of chiller-2 compressor and fan

	Quantity	Rated power	Rated current	I_m	pf	Power input	L
Compressor	4	22.3 kW	36.1 A	31 A	0.83	12.5 kW	0.60
Fan	6	2.1 kW	3.8 A	2.2 A	0.81	1.2 kW	0.69

The total power input to the chiller is the sum of compressor and fan power input

$$P_{total,in} = P_{c,in} + P_{f,in} \quad (8.8)$$

$$= 50 \text{ kW} + 7.2 \text{ kW}$$

$$= 57.2 \text{ kW}$$

Annual electrical energy consumption of chiller compressor and fan was determined separately by using equation (7.5):

Compressor: AEC = 50 kW*0.6*8760 hr = 262800 kWh

Fan: AEC = 7.2 kW*0.69*8760 hr = 43519.7 kWh

Total annual electrical energy consumed was 306,319.7 kWh.

8.2.2. Electrical power input to compressor and condenser fan of the chiller-2

The total rated power input to this chiller was 43.7 kW. The compressor and condenser fans current were noted on r, s and t wires using a clamp-meter. Using equation (7.1), (7.2) and (7.3) the power input, loading and motor efficiency is summarized in the following table 8.3.

Table: 8.3. Rated and measured values of chiller-2 compressor and fan

	Quantity	Rated power	Rated current	I_m	pf	Power input	L
Compressor	2	17.65kW	31.75A	28A	0.8	14.7kW	0.84
Fan	4	2.1kW	3.8A	2.2A	0.81	1.2kW	0.69

The total power input to the chiller is the sum of compressor and fan power input

$P_{total,in}$ = 29.4 kW + 4.8 kW

= 34.2 kW

Annual electrical energy consumption of chiller compressor and fan was determined separately by using equation (7.4):

Compressor: AEC = 29.4 kW*0.84*8760 hr = 216,336.96 kWh

Fan: AEC = 4.8 kW*0.69*8760 hr = 29013.12 kWh

Total annual electrical energy consumed was 245350 kWh.

8.2.3. Performance analysis of water chiller

The energy performance or COP (cooling output over chiller power input) of chillers depends on the heat rejection medium, ambient conditions, compressor efficiency and the load carried by the chiller. The coefficient of performance of two different water chillers is conducted in this study. These chillers utilize two different refrigerants of R – 410A and R – 407C by chiller-1 and chiller-2, respectively.

8.2.3.1. Performance analysis of water chiller-1

This chiller condenser and evaporator temperatures were noted from the chiller display monitor, which was 40°C and 5°Cof condenser and evaporator respectively.

The following values are obtained from P-h chart for R- 410A [Appendix H] to estimate the COP of the chiller (Saidur and Hasanuzzaman, 2011), (Jayesh et.al., 2014).

h_1 = 420KJ/kg, s_1 =1.75kJ/kg =s_2', h_3 =260kJ/kg =h_4, h_2' = 480kJ/kg, s_2 = 1.8kJ/kg

c_p = 1.84kJ/kg

$s_2 = s_2' + 2.3 * c_p * \log (T_2/T_2')$

1.8kJ/kg = 1.72kJ/kg +2.3 * 1.84* log $(T_2/313)$, this implies, T_2= 319k

$h_2 = h_2' + c_p\ (T_2 - T_2')$

= 480kJ/kg +1.84kJ/kg (6k)

= 491kJ/kg

Work done by the compressor

$W_c = h_2 - h_1$ = 491 kJ/kg – 420kJ/kg = 71KJ/kg

$$\text{Cop} = \frac{h_1 - h_4}{h_2 - h_1} = 160\text{kJ/kg}/71\text{KJ/kg} = 2.25$$

8.2.3.2. Performance analysis of water chiller-2

The following values are obtained from P-h chart for R-407C [Appendix I] to determine COP of the chiller (Saidur and Hasanuzzaman, 2011), (Jayesh et.al., 2014).

h_1 = 420KJ/kg, s_1 =1.8kJ/kg =$s_2{}'$, h_3 =265kJ/kg =h_4, $h_2{}'$ = 480kJ/kg, s_2 = 1.85kJ/kg

c_p = 1.54kJ/kg

$s_2 = s_2{}' + 2.3 * c_p * \log (T_2/T_2{}')$

1.85kJ/kg = 1.80kJ/kg +2.3 * 1.54* log ($T_2/313$), this implies, T_2= 317.5k

$h_2 = h_2{}' + c_p (T_2 - T_2{}')$

= 480kJ/kg +1.54kJ/kg (4.5k) = 486.93kJ/kg

Work done by the compressor

$W_c = h_2 - h_1$ = 486.93 kJ/kg – 420kJ/kg = 66.93KJ/kg

$$\text{Cop} = \frac{h_1 - h_4}{h_2 - h_1} = 155\text{kJ/kg}/66.93\text{KJ/kg} = 2.3$$

The water chiller plant layout and electrical power input to the system is summarized in the following figure.

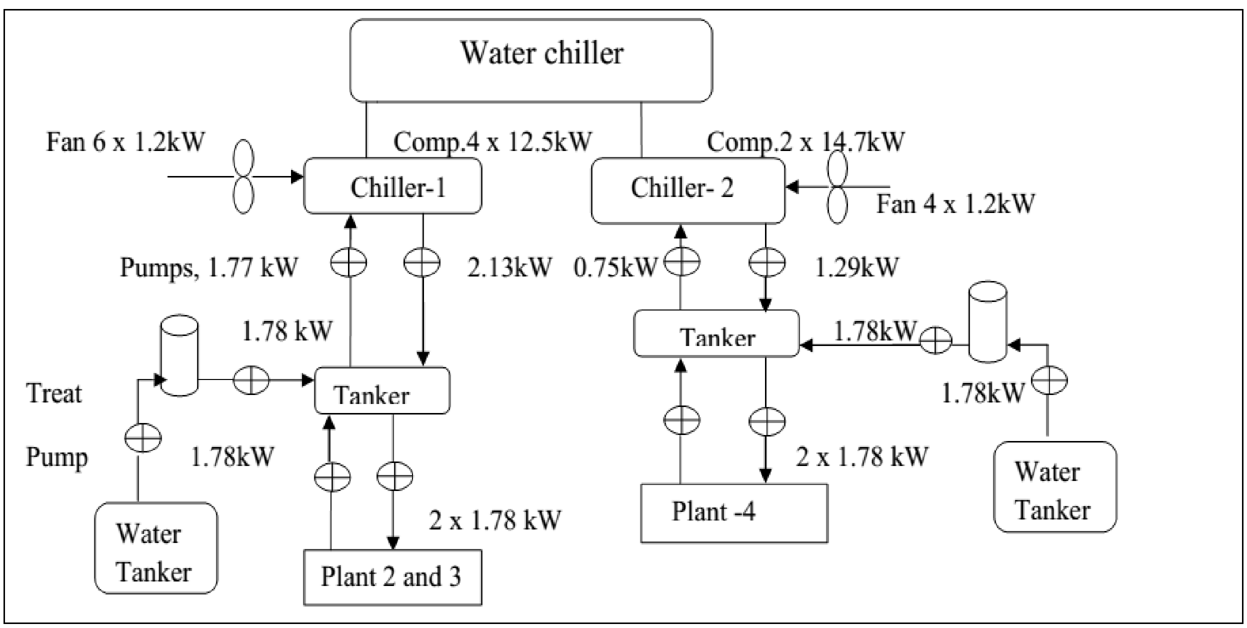


Figure: 8.1. Water chillers plant layout and the actual electrical power input

CHAPTER 9

Energy Saving Potential in the Factory

9.1. Fire tube boiler energy saving potential analysis

After detailed boiler performance assessment is conducted, different ECO is identified. This various energy efficiency opportunities in boiler system can be related to combustion, exhaust flue gas and boiler designed capacity. The following energy conservation opportunities are identified:

i. Higher heat energy loss occurred due to high flue gas temperature
ii. The boiler is working in under load condition
iii. The efficiency of boiler is highly affected by the excess air.

Reducing the flue gas temperature by installing the recuperator heat exchanger, controlling the excess combustion air by installing controller to the system is critical.

1. Combustion Air Preheat

Combustion air preheating is the most potent way to enhance the boiler efficiency and hot water generation. The temperature of exhaust gas stream can be used as the source of the heat energy and a heat exchanger can be used to transfer the heat energy to the incoming combustion air (Erhan and Kayabas , 2017). Thus combustion air gains a large portion of sensible heat that is required to take part in the combustion process. When combustion air temperature is raised by 20 °C, the boiler efficiency will be improved by 1%.

The most common use of gas-gas heat exchanger is used to preheat combustion air by passing the boiler exhaust and fresh air in different flow configuration between plates or tubes through which heat is transferred (Erhan and Kayabas , 2017).

Recuperator is a type of heat exchanger utilized for recovering the heat from the waste flue gas, generally to combustion air in order to improve the total efficiency of fire tube boiler. In addition, utilization of recuperator decreases flue gas temperature and thus, cooling expenses of flue gas, while increasing the temperature of combustion air and saving fuel. This heat exchanger also can be used for heating any gaseous substance or fresh air to fulfill a process requirement.

Theoretical heat recovery potential calculations

In order to calculate transferred heat from flue gas to combustion air, overall heat transfer coefficient must be determined

i. The amount of heat transfer is calculated;

$$Q = m_{air} * Cp_{air} * (T_{air\ out} - T_{air\ in}) = m_f * Cp_f * (T_{f\ in} - T_{f\ out}) \quad (9.1)$$

ii. The outlet combustion air temperature can be estimated;

$$T_{air\ out} = \frac{Q}{m_{air} * Cp_{air}} + T_{air\ in} \quad (9.2)$$

iii. Calculate the logarithmic mean temperature difference;

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{ln(\frac{\Delta T_1}{\Delta T_2})} \quad (9.3)$$

iv. To calculate tube side convective heat transfer coefficient;

$$Re = \frac{\dot{m} * d_i}{A_t * \mu} \quad (9.4)$$

$$h_i = \frac{k}{d_i} * 0.023 * Re^{0.8} * Pr^{1/3} \quad (9.5)$$

v. To calculate shell side convective heat transfer coefficient;

$$Re = \frac{D_e * \dot{m}}{\mu * A_s} \quad (9.6)$$

$$h_o = \frac{k}{D_e} * 0.023 * Re^{0.8} * Pr^{1/3} \quad (9.7)$$

vi. To compute the overall heat transfer coefficient;

$$\frac{1}{U_o} = \frac{do}{h_i * di} + \frac{1}{R_a} + \frac{do\ ln(do/di)}{2k} + \frac{1}{R_f} + \frac{1}{h_o} \quad (9.8)$$

vii. The heat transfer between two fluids can be calculated from;

$$Q = F_T U_o A \Delta T_{lm} \quad (9.9)$$

Thermo physical properties are used in calculation of cross flow over pipe bundle as external flow in the recuperator. Pipes inside the recuperator were designed in regular square arrangement. With the application of a recuperator, the temperature of flue gas was aimed to decrease from 184°C to 140°C, by considering the dew point temperature of dry exhaust flue gas and temperature of combustion air was aimed to increase.

Thermo physical Properties

Flue gas: $T_{f\ in}$= 184°C, $T_{f\ out}$ = 140°C, Cp_f=1.357kJ/kgk, k_f = 0.035W/mk,

μ_f = 3.03 *10^{-5} N.s/m^2

$\dot{m}_f$ = 27.16kg/kg *0.019kg/s = 0.516kg/s

Combustion air: $T_{air\ in}$= 20°C, Cp_{air}= 1.009 kJ/kg k, k_{air} = 0.03 W/mk,

μ_{air} = 18.24 *10^{-6} N.s/m^2, at 20°C

$\dot{m}_{air}$ = AAS * $\dot{m}_{fuel}$ = 26.16kg /kg fuel * 0.019kg/s = 0.497kg/s

$k_{stailess\ steel}$ = 50 W/m k

i. The amount of heat transfer from dry flue gas to combustion air is calculated using equation (9.1);

Q = 0.516 kg/s* 1.357 kJ/kgk* (184 – 140) °C

= 30.81 kW

ii. The outlet air combustion air temperature is estimated through equation (9.2);

$$T_{air\ out} = \frac{30.81\ kW}{\frac{0.497\ kg}{s} * 1.009 \frac{kJ}{kg\ k}} + 20\ °C = 81.45\ °C$$

In this study,30.81 kW heat recovery potential was determined and double pass cold, single pass hot cross flow recuperator was designed.

In this study a recuperator was designed in order to increase the combustion air temperature entering into combustion chamber by recovering the heat from dry exhaust flue gas. Recuperator is a type of heat exchanger utilized for recovering the heat from the waste flue gas, generally to combustion air in order to improve the total efficiency of facilities. In addition, utilization of recuperator decreases flue gas temperature and thus, cooling expenses of flue gas, while increasing the temperature of combustion air and saving fuel. Due to these benefits recuperators are indispensable devices in all facilities using thermal energy. Issue of selecting suitable type, dimensions, materials and flow arrangement are very significant for achieving the aimed heat recovery amount. However, most essential steps are discovering the characteristics of the fluids, design and arrangement of the facility where the recuperator will be placed and lastly operating conditions before the design step of recuperator.

The heat transfer application with pipe bundle in cross flow is a common method in many industrial facilities. Thus, in this study a cross flow recuperator is taken into account for recovering of flue gas heat to combustion air (Erhan and Kayabas , 2017)

Design of heat exchanger

iii. Calculate the LMTD using equation (9.3);

$$\Delta T_{lm} = \frac{102.55 - 120}{ln(\frac{102.55}{120})} = 111°C$$

iv. Calculate h_i assuming Φ_i = 1.0

Dimensions:

For purposes of in-tube cleaning larger tube diameters are often required for condensers and boilers to be 20 mm (3/4 in.) (Kakac, 2012). From the appendix H the estimated the outer tube diameter $3/4\ in$ with Birmingham Wire Gage (BWG) of 18 is selected. Tube pitch, P_T is usually chosen so that the pitch ratio PT/do is between 1.25 and 1.5 (Kakac, 2012).

Outer tube diameter: d_o = 0.75 in = 0.01905m

Inner tube diameter: d_i = 0.652 in = 0.01656m

Pitch: P_T = 0.0254m

Shell-diameter-to-tube-length ratio should be within limits of 1/5 to 1/15 (Basheer et.al, 2018). Normally the shell diameter is taken to be within the range 150mm to 1067mm (Kakac, 2012). For this design it is taken to be 1045 mm and the ratio of tube length to shell diameter are taken to be 8.

Tube length:

L = (8 x diameter of shell) = 8 x 1.045m = 8.36 m

Area of one tube:

A = $\pi * d_o$* L =0.5 m^2

Number of tube = 18 (assumed)

Tube per pass = 18/2 = 9

Cross section area of inner tube = $\pi {d_i}^2$ /4 = 0.0002153m^2

Total flow area = Number of tubes per pass * cross section area of inner tube

= 9 * 0.0002153m^2

= 0.00194m^2

Calculating Reynolds number and convective heat transfer coefficient of tube side through equation (9.4) and (9.5) respectively;

$$Re = \frac{0.497\text{kg/s} * 0.01656\text{m}}{0.00194*18.24*10^{-6}} = 232{,}589.5, \text{ turbulent flow}$$

$$h_i = \frac{0.0251}{0.01656} * 0.023 * (19{,}646) * 0.9, \qquad Pr = 0.71$$

= 616.4W/mk

v. Calculate h_o assuming Φ_o = 1.0

Equivalent diameter:

$$D_e = \frac{4*({P^2}_T - \frac{\pi {d_o}^2}{4})}{\pi * d_o} = 0.0241\text{m}$$

C = P_T - d_o= 0.0254m - 0.01905m = 0.00635m

Bundle diameter: $D_b = d_o * (\frac{n_t}{k_1})^{1/n_1}$

For one shell two pass, k_1 = 0.156 and n =2.291, (Basheer et.al, 2018).

D_b = 0.1513m

The bundle diametrical clearance is estimated to be 12mm;

D_s = 0.1513m + 0.012m = 0.1633m

Baffle spacing B = D_s/5 = 0.03266m

Area of the shell to be:

$$A_s = \frac{D_s\, CB}{P_T}; \qquad A_s = \frac{0.1633 * 0.00635 * 0.03266}{0.0254} = 0.00134m^2$$

Calculating Reynolds number and convective heat transfer coefficient of shell side through equation (9.6) and (9.7) respectively;

$$Re = \frac{0.0241\text{m} * 0.516\text{kg/s}}{0.00134 * 3.03 * 10^{-5}} = 306{,}280.5, \text{ Turbulent flow}$$

$$h_o = \frac{0.035}{0.0241\text{m}} * 0.023 * (24{,}484.7) * (0.493), \quad Pr = \frac{Cp * \mu}{k} = 0.12$$

$$= 403.2\text{W}/mk$$

vi. The overall heat transfer coefficient is estimated through equation (9.8)

The fouling factor of flue gas and air is taken 2000 W/m^2℃ and, 5000 W/m^2℃ of flue gas and air respectively through (Basheer et.al, 2018), (Kakac, 2012).

$$\frac{1}{U_o} = \frac{0.01905}{616.4 * 0.01656} + \frac{1}{5000} + \frac{0.01905\, ln(0.01905/0.01656)}{2*50} + \frac{1}{2000} + \frac{1}{403.2}$$

$$= 0.001866 + 0.0002 + 0.00002668 + 0.0005 + 0.00248$$

$$U_o = 197.13\ W/m^2k$$

The heat transfer between two fluids is estimated through equation (9.9);

$$Q = F_T U_o A \Delta T_{lm}$$

$$P = \frac{T_{c2} - T_{c1}}{T_{h1} - T_{c1}} = 0.374, \quad R = \frac{T_{h1} - T_{h2}}{T_{c2} - T_{c1}} = 0.7166$$

$$\alpha = [\frac{1-RP}{1-P}]^{1/N_{shell}} = 1.17$$

$$S = \frac{\alpha - 1}{\alpha - R} = 0.3749$$

$$F_T = \frac{\sqrt{R^2 + 1} \ln [\frac{1-S}{1-R*S}]}{(R-1) \ln [\frac{2-S(R+1-\sqrt{R^2+1})}{2-S(R+1+\sqrt{R^2+1})}]} = 0.96$$

Calculate the required surface area

$$Q = F_T * U_o * A * \Delta T_{lm},$$

$$A = \frac{Q}{U_o * F_T * \Delta T_{lm}} = \frac{30.81kW}{197.13\ W/m^2k * 0.96 * 111℃} = 1.47\ m^2$$

There is available area for the installation, so is visible

By utilizing the recuperator, cross flow heat exchanger ,one fluid unmixed (combustion air) and flue gas mixed, combustion air will be heated from 20 °C to 81.4 °C and flue gas will be cooled from 184°C to 140 °C.

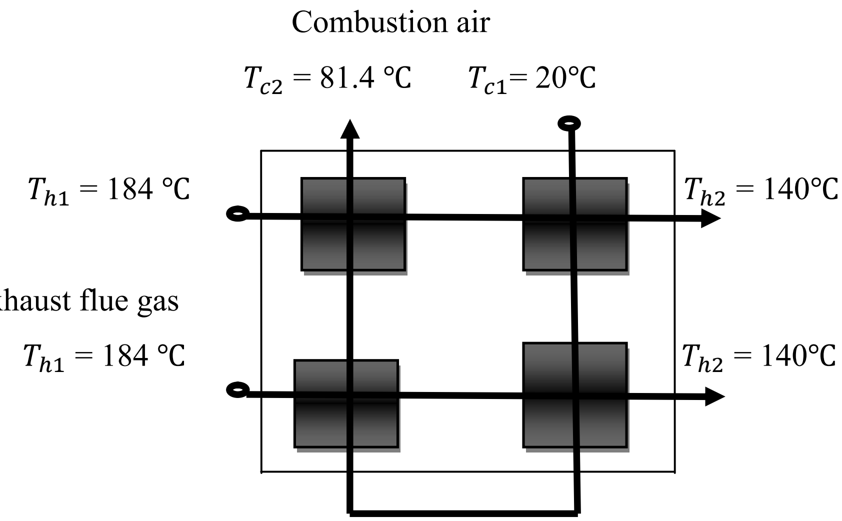


Figure: 9.1. Double pass cold, single pass hot cross flow heat exchanger

The increment of combustion air temperature by 20℃ leads the increment of 1% boiler efficiency.The annual energy saved will be:

$$AES = \dot{m}_f * GCV [\eta_{new} - \eta_{old}]$$

$$= 0.0188 \text{ kg/s} * 43 \text{ MJ/kg} [0.8453 – 0.8146]*3600*24*365$$

$$= 782.6 \text{ GJ/year}$$

- The implementation cost of utilizing recuperative heat exchanger to pre heat combustion air with its specification of flue gas - combustion air, mixed- unmixed with operating temperature range of 10 – 200℃ , is estimated as:

Cost estimation of the heat exchanger system

	Estimated cost ETB
Purchase price	179,604.6
Freight and handling	91,387
Installation	45,264
Opportunity cost	39,675
Total initial investment cost	355,928.6

Cost benefit analysis of the system

The annual energy saved of 782.6 GJ/year, implies that about 18200 kg/year of fuel is saved. That means 21510 liter of fuel is saved, with the estimated saving cost of 387,188 ETB.

Cash flow

In this study, it is estimated that the heat exchanger can safely works properly for more than 12 years.

Year	1	2	3	4	5	6	7	8	9	10	11	12
Benefit (ETB)	387,188	387,188	387,188	387,188	387,188	387,188	387,188	387,188	387,188	387,188	387,188	250,000
Cost (ETB)	355,928.6	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	Salvage value

Present value analysis

Let's take a 17% interest rate which is an interest rate similar to that which is used by the commercial bank of Ethiopia when it lends money. Equation used to calculate the present value of future money is:

$$N = \frac{M(n)}{(1+i)^n} \qquad (9.10)$$

Where, N- is the present value of future money, $M(n)$ - is the value of money n years, i – is the interest rate, n – is the number of years.

Using the equation (9.10) the present value of the benefit is 1,910,594.75 ETB. And the present value of the cost is 344029.861ETB. Hence, benefit/cost =5.55.

The ratio of the benefit to cost indicates that the use of a heat recovery system is financially feasible.

The payback period will be $= \frac{\text{Total initial investment cost}}{\text{saving cost}} = \frac{355{,}928.6}{387{,}188} = 0.92 \text{ year} \cong 336$ days

2. Excess air control

From the boiler performance assessment, it is observed that about 18% and 19% waste heat energy from the energy input of gross calorific value. The energy waste is directly connected to excess air supplied to burner. The excess air supplied to the burner is about 85.84 and 90.5 of boiler 1 and 2, respectively.

Excess air is required in all practical cases to ensure complete combustion. The optimum excess air level for boiler efficiency which uses diesel fuel oil will be 15-20%. Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency (Barma et.al, 2017). The energy lost of at maximum of 20% excess air can be estimated as follows:

a. Theoretical air required for combustion is estimated through equation (5.2);

RA = [(11.6 * 84.79) + {34.8 *(12.21 – 0.5/8)} + (4.35 *0.5)]/100

= 14.08 kg of air/kg of fuel

b. Actual mass of air supplied/ kg of fuel is determined through equation (5.4);

AAS = (1+ 20/100) * 14.08

= 16.9 kg/kg of fuel

Excess air quantity = AAS – RA

= 16.9kg of air – 14.08 kg of air

= 2.82 kg of air

c. Heat loss due to dry flue gas is recalculated through equation (5.5);

$$L_1 = \frac{17.9 * 1.357\text{kJ/kg} * (180 - 28)}{43MJ/kg} * 100$$

= 8.58%

The heat loss due to dry flue gas is minimized from 13.37% to 8.58%

The most common method to control excess air is the continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow.

The annual energy saved in reduction of excess air to minimum of 20% will be:

AES = $\dot{m}_f$ * GCV [$\eta_{new\ boiler}$ - $\eta_{old\ boiler}$]* 3600s * 24* 365

= 0.0188 kg/s * 43 MJ/kg [0.8625 - 0.8146]*3600*24*365

= 1221 GJ/year

It is observed that about 33,560 liter fuels and 604,085 ETB cost can be saved annually.

The total investment cost of oxygen analyzer to control excess combustion air is estimated to 71,256 ETB. It reads the amount of combustion air which is passing to the burner of the furnace. The operator adjusts the level of excess air to the minimum level that can facilitate complete combustion.

If the adjustment is to 20% excess combustion air it payback period will be:

$$\text{Payback period} = \frac{total\ investment\ cost}{saved\ cost} = \frac{71{,}256}{604{,}085} = 43 \text{ days}$$

9.2. Energy saving potential analysis of electrical motors machine drives

It was observed from visiting that there are some electric motors which are weak, dirty, dusty, poorly ventilated and inefficient in the factory. Electrical energy saving can be achieved through:

i. Replacing standard electric motors with energy efficient motors
ii. Turning off equipment when not in use
iii. Performing proper housekeeping and operation of electric drives, as good ventilation reduces energy loss due to heating.

i. Replacing standard electric motors by energy efficient motors

Selecting energy-efficient motors is an important strategy for reducing motor system life-cycle costs because they reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

The total number of normal or standard electrical motors used in this industry is 278 of three different pasta and macaroni production plant lines. The recommended operating hours of standard electrical motors is less than 5000 hrs annually (Saidur and Hasanuzzaman, 2011). Motors operating at the above stated conditions should be replaced with the energy efficient motors in order to avoid the major power loss. Accordingly, the normal motors used in the industry could be replaced with the energy efficient motors (EEM) one by one.

An EEM produced the same shaft output power, but uses less input power than a standard efficiency motor. EEM has also less loss compare to the standard motor. EEM core become low resistance material. So, the cost of EEM is high compare to the standard motor.

EEM is manufactured using the same frame as a standard motor. But they have some differences:

a. Higher quality and thinner steel laminations in the stator.

b. More copper in the winding.
c. Optimized air gap between the rotor and the stator.
d. Reduced fan losses.
e. Closer machining tolerances.
f. A greater length.
g. High quality aluminum used in the rotor frame.
h. The EEM has a greater efficiency than a standard motors: therefore they have less operating costs.
i. EEM has a lower slip so they have a higher speed than standard motors.
j. EEM can reduce maintenance costs and improve operations in industry due to robustness and reliability.
k. Increasing of productivity.

Annual Energy saving by replacing normal motor with energy efficient motor is estimated by using the following equation:

$$\text{AES} = h_p * L * 0.746 * h_y * N_m * \left\{\frac{1}{\eta_{nm}} - \frac{1}{\eta_{ee}}\right\} *100 \quad (9.11)$$

The efficiency of standard and high efficiency motors at different loads (Saidur and Hasanuzzaman, 2011).

Table: 9.1. Reference efficiency of standard and high efficiency motors at different loads

	Load (50%)		Load (75%)		Load (100%)	
Motor hp	E_{nm}	E_{ee}	E_{nm}	E_{ee}	E_{nm}	E_{ee}
1	70.05	75.28	74.43	79.49	77.00	80.97
1.5	76.04	80.06	78.03	81.28	78.50	82.55
2	77.20	80.02	79.29	83.07	81.00	83.55
3	77.78	82.44	82.39	84.55	81.50	85.01
4	81.07	83.69	84.73	85.24	82.90	85.96
5	70.10	77.20	73.80	81.30	82.50	90.80
7.5	71.00	77.60	74.70	81.70	83.50	91.30
10	73.10	78.50	77.00	82.60	86.00	92.30
15	73.60	78.70	77.50	82.90	86.60	92.60
20	74.20	79.20	78.10	83.40	87.30	93.20
25	75.40	79.80	79.40	84.00	88.70	93.90
30	76.00	80.20	80.00	84.40	89.40	94.30

The summary of annual energy saving by replacing normal motor by energy efficient motor of standard electrical motors that are equipped in production plant lines (2, 3, 4);

Table: 9.2. Annual electrical energy saving opportunity of using high efficient motors

$P_r[kW]$	$\%\eta_{nm}$	$\%\eta_{ee}$	AES [kWh]
0.2	63	79.49	2939.4
0.25	66	75.28	6028.5
0.55	68	75.28	14676.5
0.75	68	75.28	51367.8
1.1	76	81.28	16539.3
3	68	85.24	6754.3
3.5	73	85.24	20438.8
6.5	77	82.60	4666.4
7.5	75	82.60	6237.3
20	72	84.00	133033.1
			Total = 262, 681.4

Accordingly, annual energy saving of replacing normal / standard electric motors of 178 to high energy efficient motors results reduce in electric power cost of the factory.

The amount of bill saved in ETB will be estimated as:

Total energy saved = 262, 681.4 kWh

Since the factory is high voltage customer, the annual bill saved will be:

ABS = 262, 681.4 kWh * 2.61 ETB/kWh = 685,598.5ETB

Depending up on the motors rated capacity, the purchased price of 178 high efficient motors are estimated as follows:

Table: 9.3. Estimated price of highly efficient motors

Hp	Quantity	Estimated price	Total	Estimated price ETB
1	165	$42/unit	$6930	200970
1.5	1	$50/unit	$50	1450
5	5	$136/unit	$680	19720
10	2	$190/unit	$380	11020
25	6	$372/unit	$2232	64728
Total	178			297, 888 ETB

The total cost of energy efficient motors is estimated 423, 683ETB and the payback period will be

$$PBP = \frac{\text{total investment cost}}{\text{annual bill saving}} = \frac{423{,}683\ ETB}{685598\ ETB} \simeq 0.62\text{year} = 226\ \text{days}$$

Cost estimation of the high energy efficient motors

	Estimated cost ETB
Purchase price	297, 888
Freight and handling	34,800
Installation	60,320
Opportunity cost	30,675
Total initial investment cost	423, 683

Cost benefit analysis of the system

The annual energy saved of 262, 681.4 kWh, with the estimated saving cost of 685,598.5 ETB.

Cash flow

In this study, it is estimated that the high energy efficient motor can safely works properly for more than 10 years.

Year	1	2	3	4	5	6	7	8	9	10
Benefit (ETB)	685,598.5	685,598.5	685,598.5	685,598.5	685,598.5	685,598.5	685,598.5	685,598.5	685,598.5	450,000
Cost (ETB)	423, 683	10000	10000	10000	10000	10000	10000	10000	10000	Salvage value

Using the equation (10.10) the present value of the benefit is 8,418,753 ETB. And the present value of the cost is 398,081 ETB. Hence, benefit/cost =21.

The ratio of the benefit to cost indicates that the use of a heat recovery system is financially feasible

ii. Turning off equipment when not in use

Adopting energy efficiency and implementing conservation measures can result in significant energy savings. It was observed in this industry that there is energy consumption when energy consuming equipment when they are not in use. Each motor left on, no matter how small, results in a large amount of wasted energy when considered over a long period. This particular analysis considered savings that could be made if machines and equipment are switched off when not in use.

9.3. Energy saving potential of pumps

During walkthrough in the factory, excessive flow noise, highly throttled flow control valves, heavy use of bypass lines, frequent replacements of bearings and seals, and intermittent pump operation were observed. Those observed behaves are the effect of oversized pump.

Systems with significant annual operating hours incur high operating and maintenance costs relative to initial equipment purchase costs. Inefficiencies in high-run-time, oversized systems can add significantly to annual operating costs; however, costly inefficiencies are often overlooked when ensuring system reliability. The cost of over sizing pumps extends beyond energy bills. Excess fluid power must be dissipated by a valve, a pressure-regulating device, or the system piping itself, which increases system wear and maintenance costs. Valve seat wear, which results from throttling excess flow and from cavitations, creates a significant maintenance problem and can shorten the interval between valve overhauls. Similarly, the noise and vibration caused by excessive flow creates stress on pipe welds and piping supports; in severe cases, this can erode pipe walls. The alternative correct measure of the oversized pump problem is identified as installation of adjustable speed drive (ASD).

i. Install an adjustable speed drive (ASD)

Pumps that experience highly variable demand conditions are often good candidates for ASDs. The most popular type of ASD is the variable frequency drive (VFD). VFDs use electronic controls to regulate motor speed, which, in turn, adjusts the pump's output. The principal advantage of VFDs is better matching between the fluid energy that the system requires and the energy that the pump delivers to the system. As system demand changes, the VFD adjusts the pump speed to meet this demand, reducing the energy lost to throttling or bypassing excess flow. The resulting energy and maintenance cost savings often justify the investment in the VFD.

9.4. Energy saving potential of air compressor

In order to save energy loss in air compressor the following activities are recommended.

- Maintain compressed air systems
- Reduce leaks
- Turn off unnecessary compressed air
- Dryer cleaning and maintenance
- Properly size regulators
- Clean the area around compressor inlet duct from dirt and shrubs in weekly or daily basis.
- Regularly inspect the function of compressor air filter.

9.5. Energy saving potential analysis of water chillers

The both chillers are working below minimum standard of coefficient of performance. In ASHRAE 2009, the minimum chillers performance standard for air cooled with condenser, vapor compression type water chiller is 2.80. In this study COP of both chillers were less than the minimum standards. Therefore, this study identifies ways of achieving coefficient of performance of chillers by:

i. Automatic condenser tube cleaning

Since it is not practical to manually clean condensers on a regular basis, automatic condenser tube cleaning systems should be used. The two main types of condenser cleaning systems are brush type and ball type. A typical system using sponge balls for cleaning tubes. These sponge balls have a slightly larger diameter than the inside bore of the condenser tubes. The balls are circulated through the tubes at regular intervals. As the balls travel through the tubes, scale and fouling deposits are removed. After passing through the tubes, the balls are collected by a strainer. Thereafter, the balls are returned to the cleaning section for automatic cleaning and are injected back again after a pre-set time.

ii. Use of water-cooled chillers

Water-cooled chillers operate at a lower condensing pressure than air-cooled chillers. The lower condensing pressure is due to the rejection of heat to condenser water which is first cooled to a temperature a few degrees Celsius above the wet-bulb temperature of the ambient air (by the cooling towers).

In air-cooled chillers, heat is directly rejected to the ambient air and the heat transfer is dependent on the dry-bulb temperature of the air. Further, the heat transfer in the water-cooled shell and tube heat exchangers is more effective than in finned type air-cooled condensers.

The lower condensing pressure leads to a lower pressure differential between the evaporator and condenser which results in lower power consumption by the compressor. Therefore, water-cooled chillers are far more efficient than air-cooled chillers. Although water-cooled chillers are more efficient, they need cooling towers, condenser water pumps and a constant supply of water (to a make-up for water evaporation at the cooling tower).

iii. Use of alternative cooling systems

Water from a cooling tower can be used for heat removal, instead of chilled water or low temperature liquid that requires more energy intensive refrigeration systems to produce.

iv. Ensure insulation

Care should be taken not to only insulate the main body of the equipment, but also the fittings such as valves and flanges.

v. Chiller replacement

Can be replaced with high efficiency chillers with efficiency of as high as 0.49 kW/RT, which are currently available in the market.

Chillers with VSD compressors can be considered for applications with high variable loads.

CHAPTER 10

Results and Discussions

10.1. Fire tube boiler heat balance

The heat balance is an attempt to balance the total energy entering the boiler against leaving the system in different forms. The Figure 10.1 illustrates the heat balance and different losses occurring while generating hot water.

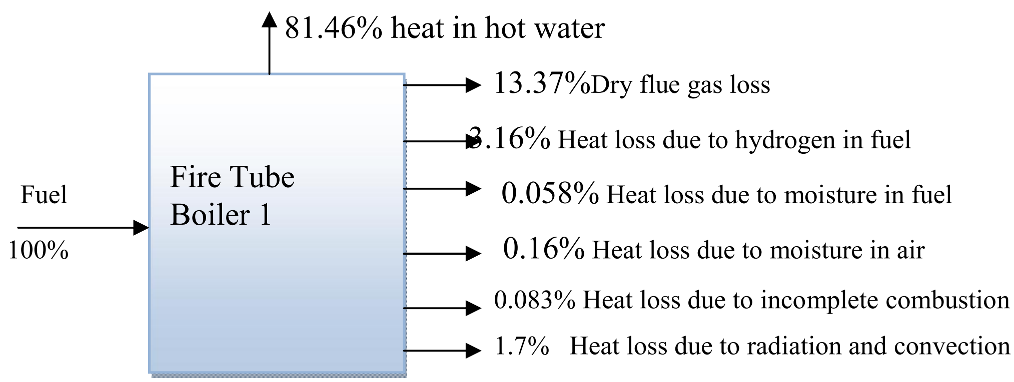


Figure: 10.1. Percentage heat balance from Fire tube boiler-1

The energy sankey diagram of the boiler is drawn to represent the thermal energy input from fuel oil to the hot water boiler, the total heat lost and the output thermal energy to the dryer - 2 and dryer -3. The following sankey diagram represents the thermal energy balance in boiler-1.

As it is seen in the following sankey representation of boiler-1, about 149.9 kW heat losses was incurred mostly due to dry flue gas, hydrogen in the fuel and convection and radiation through boiler surface. It is also estimated that about 539.6MJh thermal energy is lost hourly. This indicates nearly 12.55 kg (i.e.14.83 liter) of fuel is lost per hour and about 2.21 million ETB lost per annum.

The following sankey diagram represents the heat balance of boiler-1.

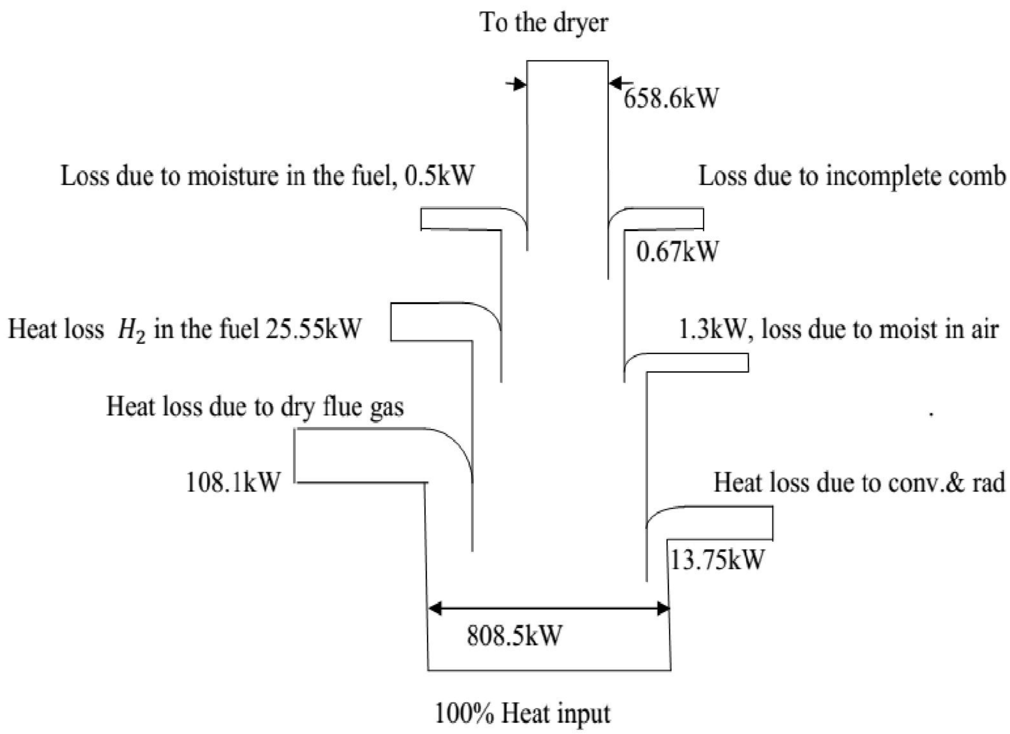


Figure: 10.2. Sankey energy input and loss representation of boiler -1

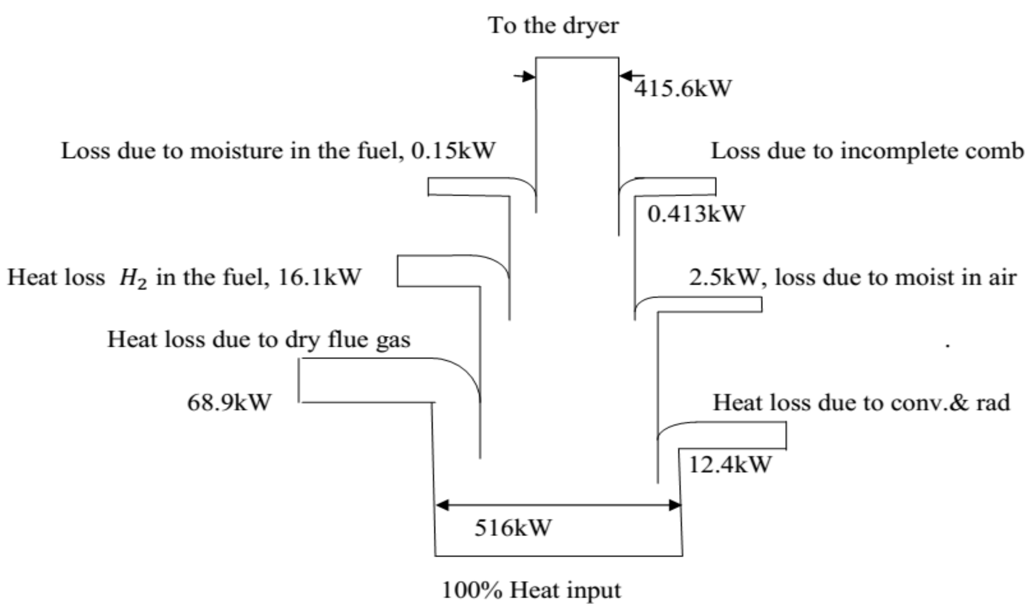


Figure: 10.3. Sankey diagram representation of boiler- 2

As it is seen in the above sankey representation of boiler-2, about 100.4kW heat loss was incurred mostly due to dry flue gas, hydrogen in the fuel and convection and radiation through boiler surface. It is also estimated that about 361.4MJ thermal energy is lost hourly. This indicates nearly 8.15kg (i.e.9.63 liter) of fuel is lost per hour and about 1.43 million ETB lost per annum

10.2. Specific energy consumption

Specific energy consumption (SEC) is an important factor that determines the energy situation in a typical industry. The annual specific energy consumption in the factory identified as 5.478 MJ/kg, of this 0.778MJ/kg thermal energy and 4.7MJ/kg electrical energy.

10.3. Equipment wise energy consumption

In general, after detailed thermal energy consumption was conducted, 26%, 36% and 38% of total annual thermal energy of 7,376,971 kWh was consumed by plant-2, plant-3 and plant-4 respectively.

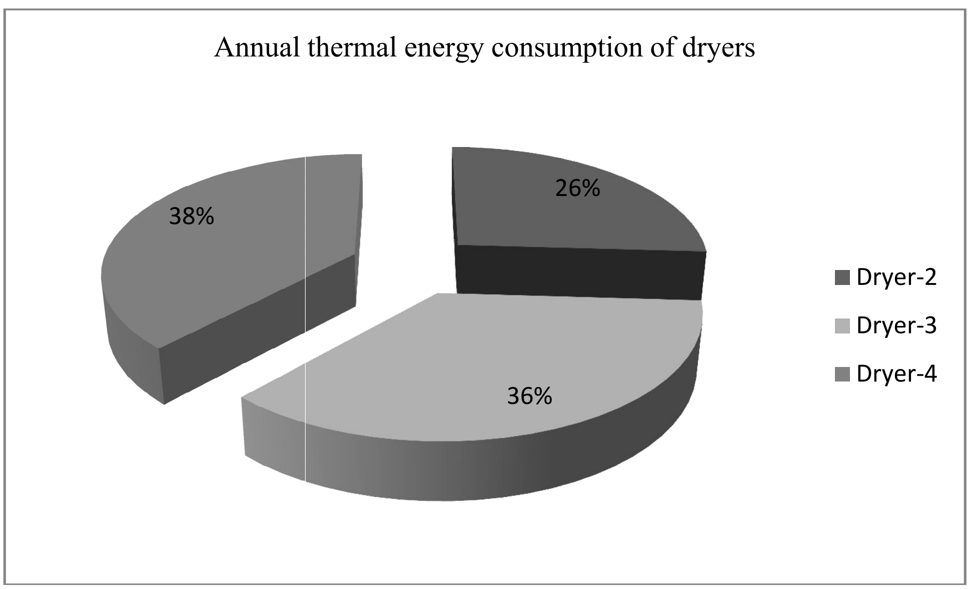


Figure: 10.4. Thermal energy consumption of plant-2, -3 and -4 dryers

It is observed from the analysis that the industrial driving motors of plant-2, plant-3and plant-4 were consumed about 20%,25%,8% of the total 20,480,377 kWh annual electrical energy consumed by the industry respectively and about 47% of the total electrical energy were consumed by the pump motor, air compressor, chiller and lighting systems in the factory.

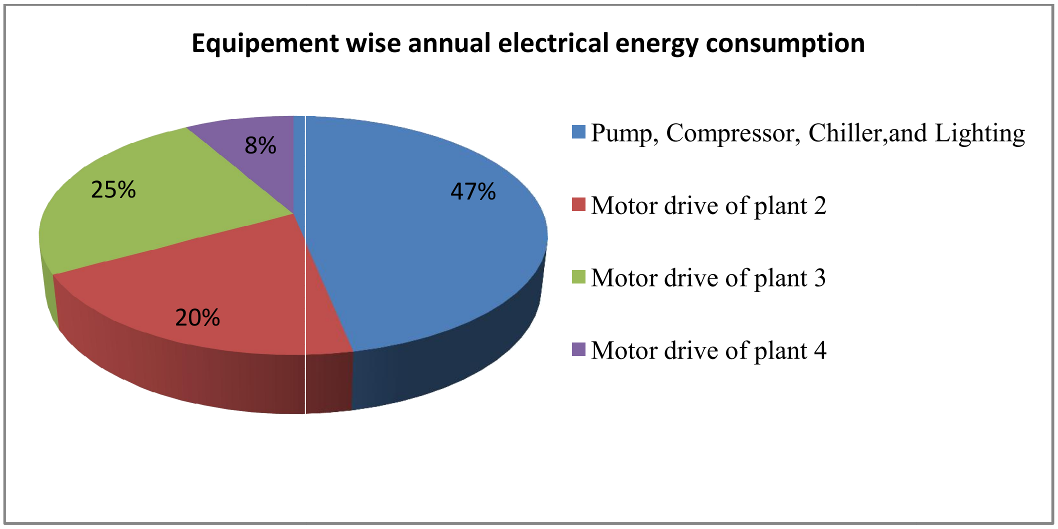


Figure: 10.5. Equipment wise annual total electrical energy consumption

The thermal energy loss in the factory that was conducted through detailed thermal energy lost from boilers and dryers in kWh per day were summarized as in figure 10.6.

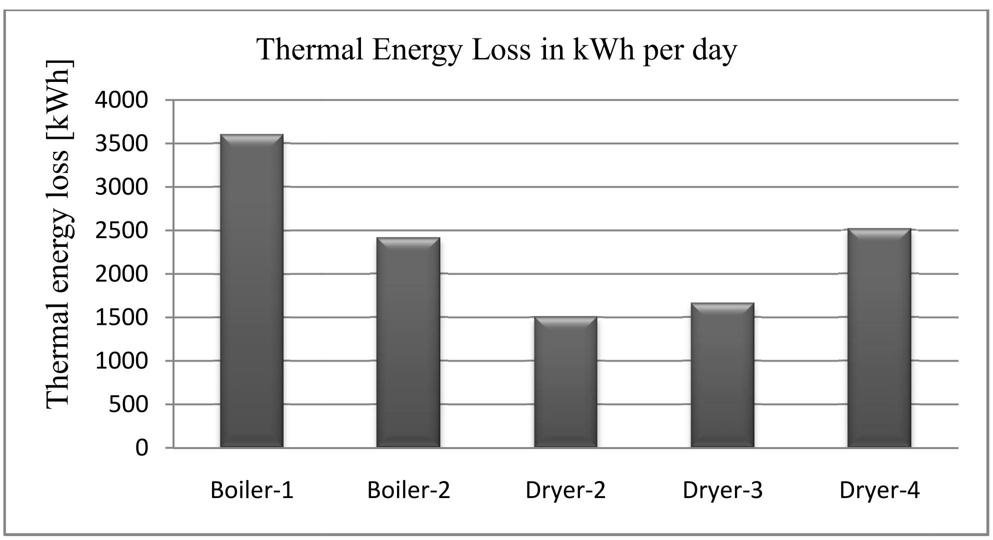


Figure: 10.6. Daily thermal energy loss in the factory

10.4. Plant wise electrical machine drives energy consumption

As it is observed from previous analysis about 3%, 9%, 19% and 69% of total annual electrical energy consumption of 36799MWh (i.e. 132.48 TJ/year) is consumed by machine drives of cooling to package zone, from mixer to pre-dryer zone, pre-dryer zone and dryer zone respectively of plant line-2 and plant-3. The summarized annual electrical energy consumption of plant line-2 and plant-3 is shown in Figure 10.7.

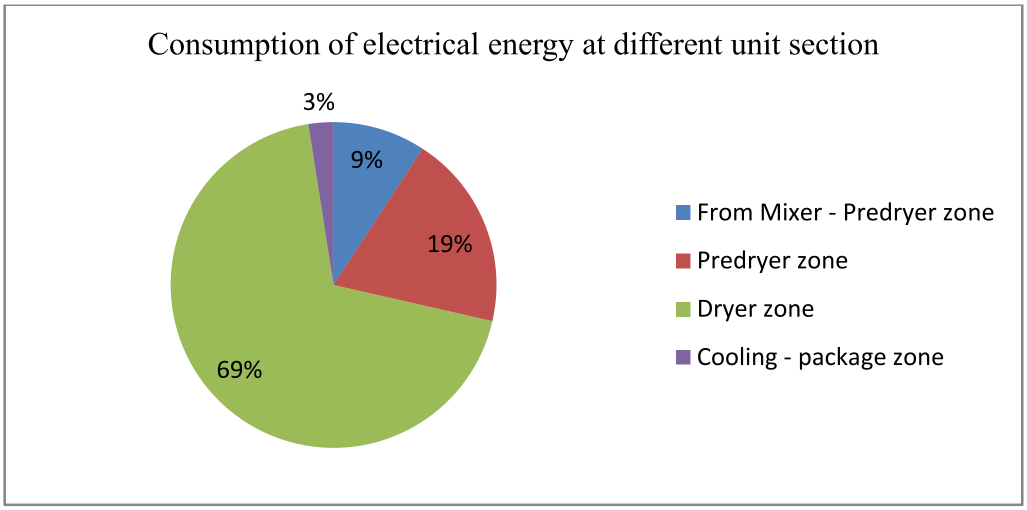


Figure: 10.7. Electrical energy consumption of plant-2 and-3 at different unit sections

It is observed that about 1%, 20% and 79% of total annual electrical energy consumption of 24.36 TJ/year is consumed by machine drives of cooling to package zone, inlet to dryer zone, and dryer zone respectively of plant line-4. The summarized annual electrical energy consumption of plant line-4 is shown in figure 9.8.

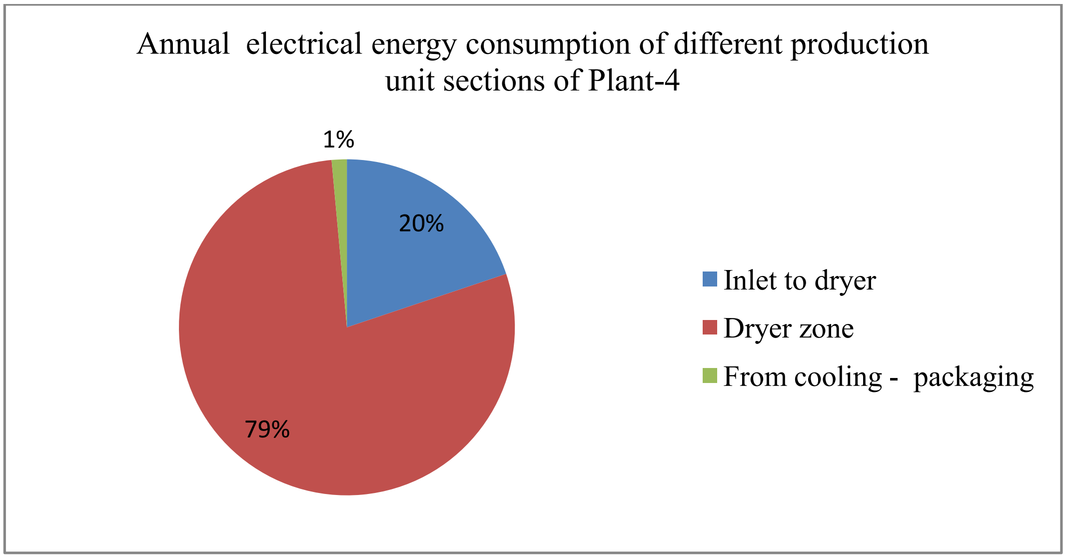


Figure: 10.8. Electrical energy consumption of plant-4 at different unit sections

The total annual electrical energy loss of driving electrical motors of plants -2, -3 and -4 is estimated to 40.78TJ/year as taking the average motors efficiencies of 74% and the total annual electrical energy consumption of 156.84TJ/year.

The following Figure 10.9 illustrates the overall pasta and macaroni factory annual energy flow.

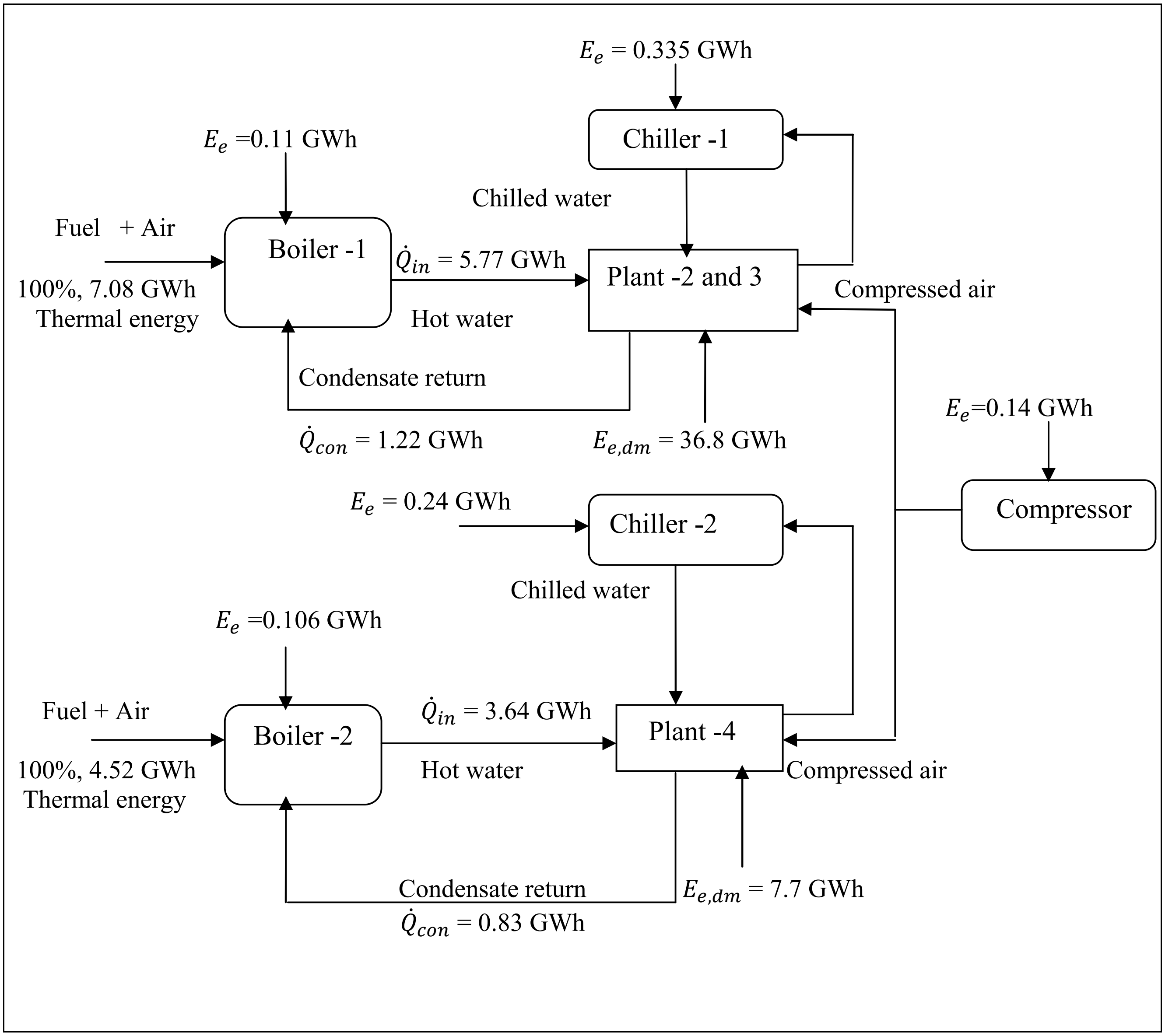


Figure: 10.9. The overall annual energy flow in the factory

One of the aims of the detailed energy analysis is to identify bad practices, inefficient equipment and poor energy habits to save power consumed. This study identifies the factory annual energy saving potential through different ways of energy recovery and energy efficient technology approaches. It is summarized in the Figure 10.10.

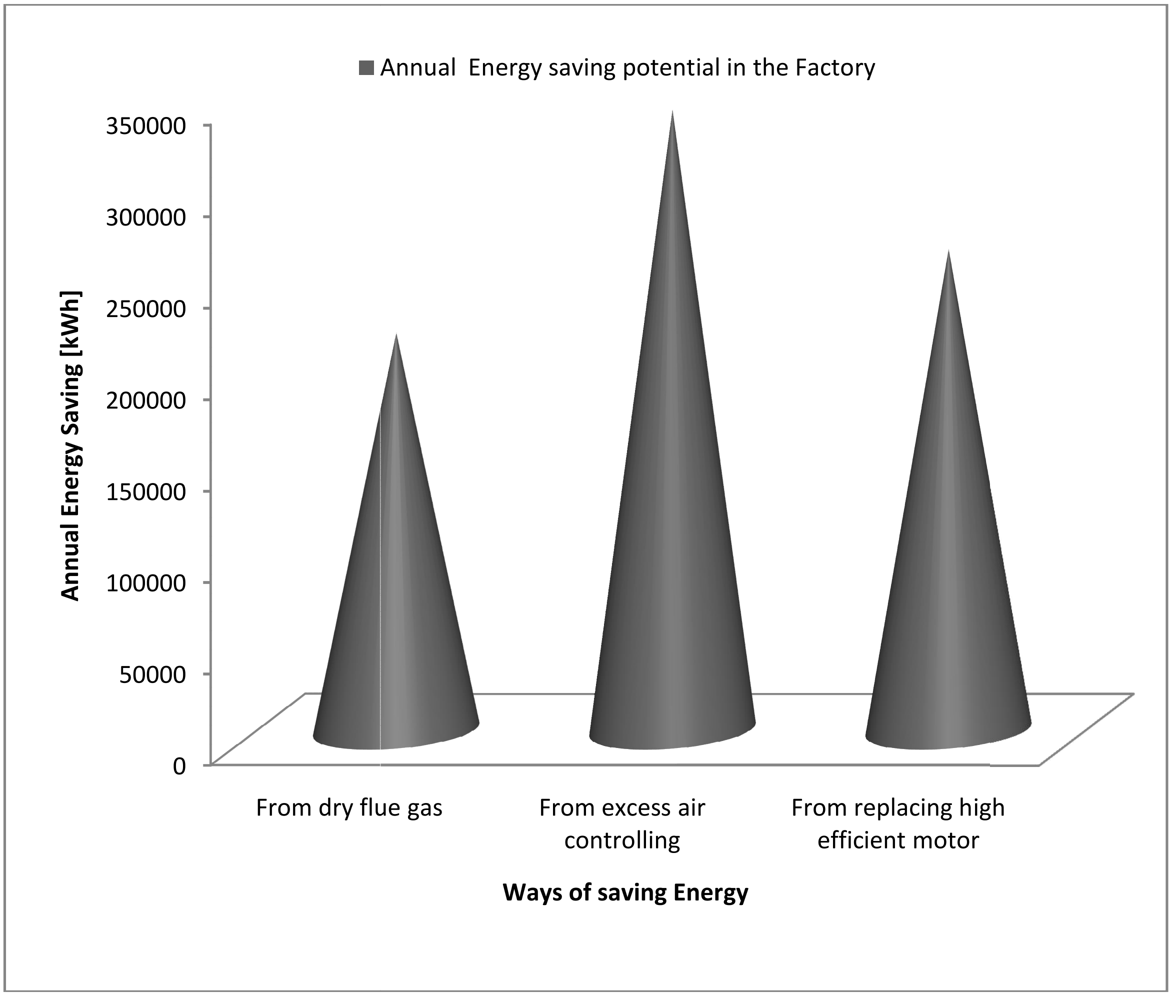


Figure: 10.10. Annual energy saving potential in the factory

CHAPTER 11

Conclusions and Recommendations

11.1. Conclusions

Adopting energy saving opportunities in manufacturing industries is needed for ensuring a sustainable industrial development in both developed and developing countries. In this study the Africa P.L.C. (Pasta and Macaroni) factory's performance of energy consumption and suggested ways of energy savings are identified. It is investigated that, the major sources of energy in this factory are electrical and thermal energy from the fuel. During walkthrough energy audit, the power rating, operation time of energy consuming equipment and machineries are identified.

In this study different instruments are used to measure actual measurement values of current, power factor, flue gas characteristics, and flows, surface temperature of the boiler, temperature of hot water and different laboratory measurements are used. For the case where direct measurement is difficult data are taken from reading boards. The data are then analyzed to investigate the energy performance of energy consuming equipments and conducted the annual energy consumption patterns in the factory.

Fire tube boilers are significant portion of the factory to facilitate the drying process. However, the typical boiler efficiencies are 81% and 80% of boiler-1 and boiler-2, respectively. The remaining part of the energy is lost as different forms of wasted heat. To evaluate the efficiency of the boiler and the amount of heat that is wasted from the boiler, performance analysis of boiler is performed. This helps to quantify the amount of heat lost through different sources and identify the potential source of waste heat.

The efficiency of the boiler can be improved by taking measures to control the potential of waste heat sources. Heat loss from the boiler occurs in several ways, and dry exhaust flue gas loss is the major source of heat loss among other sources of heat loss. Due to the limitation of acid dew point of stack gas this loss cannot be eliminated, but could be minimized by recovering waste heat from the boiler exhaust and utilizing the recovered waste heat within the boiler system. Energy saving measures for boiler has also been reviewed and discussed in detail in this study. Different types of energy saving techniques such as excess air control, improving combustion efficiency, and utilization of waste heat content of flue gas have been reviewed.

The results of the energy performance analysis in the factory has showed that 26%, 36% and 38% of total annual thermal energy of 7.4 GWh was consumed by dryers of plant-2, plant-3 and plant-4, respectively. It is also observed from the analysis that the industrial driving motors of plant-2, plant-3 and plant-4 are consuming about 20%, 25%, 8% of the total 20.48 GWh of annual electrical energy consumed by the industry, respectively and about 47% of the total electrical energy were consumed by the pump motor, air compressor, chiller and lighting systems in the factory.

This study also identifies 34.45 TJ/year and 40.96 TJ/year of total thermal energy and total electrical energy respectively is lost annually. Using different energy saving proposals 2,003 GJ/year and 945.65 GJ/year total thermal energy and total electrical energy can be saved.

Since the electric motor takes up a substantial amount of the total energy used in this factory, energy-savings strategies using high efficient motors in place of standard motors can reduce energy consumption of the motors and can save 262,681.4 kWh energy annually.

Table: 10.1. Summary of annual energy saving opportunities of the factory

	Energy Saving opportunity	Annual energy saving	Annual bill saving [ETB]	Investment cost [ETB]	Payback period
1.	Heat recovery from dry exhaust flue gas	782.6 GJ/year	387,188	355,928.6	336 days
2.	Excess air controlling using oxygen analyzer	1221 GJ/year	604,085	71,256	43 days
3.	Replacement of normal motors by energy efficient motors	262,681.4 kWh	685,598	423,683	226 days

11.2. Recommendations

There are a lot of energy-efficient technologies and practices that are proven, cost-effective, and available for implementation today. These opportunities are applicable at the component, process, facility, and organizational levels. Preliminary estimates of savings in energy and energy related costs have been provided for many of the measures, based on case study data from the factory. Typical investment payback periods and references to further information have been provided, where available. To be successful, establish a focused and strategic energy management program that helps the factory should implement energy efficiency measures to ensure continuous improvement. This study assesses energy utilization systems and identifies annual losses and energy saving opportunities. The expected energy saving opportunities relatively small, their cumulative effect across an entire facility may be quite large. Many measures have relatively short payback periods and are therefore attractive economic investments on their own. The degree to which these measures are implemented will vary among plants and end users, but continuous evaluation of your facility's energy profile will help to identify further cost savings over time. The energy efficiency measures presented in this study are economically feasible and a potential benefit of each implementation is recommended to the factory production practices.

During conducting this study there are challenges in regards to recover energy lost from the dryer of production process. It is due to lack of instruments that measure the actual amount of hot air which holds latent heat with in the moisture evaporation from pasta since there is a disturbances at inlet and outlet to drying chambers.

As it is mention above in conclusion section of this study huge amount of thermal and electrical energy is lost. So it needs further study with a sufficient and efficient industrial energy analysis tools in minimization of energy lost and further recover it.

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Appendix A: Fire tube boiler specification

1. Specification of boiler Sile S.P.A

a. Model : PAS 165
Maximum working pressure: 5 bar
Heat output: 1919 kW
Burner output: 168 kg/hr (diesel)
Made: 43010/TV – 2009
Burner type: P 200 T/N

b. Model : PAS 165
Maximum working pressure: 5 bar
Heat output: 1919 kW
Burner output: 162 kg/hr (diesel)
Made: 43977/TV – 2012
Burner type: P 200 T/G

Appendix B: The fuel properties and flue gas measured values

	Flue gas measured values	
Fuel properties	Boiler #1	Boiler #2
C content: 86.79 % H_2 content: wt 12.21 % S: wt 0.5 % O_2 content : 0.5% Moisture content: 2% Specific gravity: 0.8461 Flash point: 112.3 °F = 44.6°C GCV: 43 MJ/kg, NCV:38.46MJ/kg	T_f= 184°C T_a= 28°C CO_2= 8.4% by volume O_2 = 9.7% by volume CO = 7.8% by volume	T_f= 180°C T_a= 28°C CO_2= 8.6% by volume O_2 = 9.98% by volume CO = 15.4% by volume

Appendix C: the fire tube boiler dimensions and measured Temperature

Parameters		Measured temperature	
Diameter = 1.3m	Boiler parts	Boiler #1	Boiler #2
Length = 3.25m	Cylindrical Surface	65℃	60℃
Ambient temperature = 28℃	Front surface	90℃	97℃
Wind velocity = 2.5m/s	Bottom	70℃	73℃

Appendix D: Rated power and current of electrical motors of plant -2

Electrical motors	Function area	Quantity	Rated power[kW]	Rated current[A]
M201A-M202C	Pre-dryer ventilation U_{1-2}	6	1.5	3.3
M203A-M205C	Pre-dryer ventilation U_{4-5-6}	9	1.1	2.6
M208	Wet air inlet heating	1	1.5	3.3
M210AB	Pre humidity extraction	2	2.2	4.8
M221-M224	Pre dryer pump units	4	0.55	1.47
M301A-M310C	Dryer ventilation units	30	0.75	1.8
M326	Dryer pump zone 2	1	0.55	1.47
M390-M391	Dryer humidity extraction	2	0.75	1.8
M401A-M402C	Cooler ventilation units	6	0.75	1.8
M501	Accumulator	1	0.37	1.38
M614	Stripper	1	0.55	11.47
M615	Belt	1	0.75	1.85
M616	Cutting disc	1	2.2	4.8
M625	Dust blower	1	0.25	0.72
M101-M200	From mixer to pre-dryer	19	4.69	-
		Total=85	Total=149.28	

Appendix E: Rated power and current of electrical motors of plant-3

Electrical motors	**Function area**	**Qty**	**Rated power[kW]**	**I_r[A]**
M201A-M203D	Pre-dryer ventilation U_{1-2-3}	12	1.5	3.4
M204A-M206D	Pre-dryer ventilation U_{4-5-6}	12	1.1	2.6
M208	Wet air inlet heating	1	1.5	3.3
M210AB	Pre humidity extraction	2	2.2	4.8
M221-M225	Pre dryer pump units	5	0.55	1.5
M301A-M312D	Dryer ventilation units	48	0.75	2.1
M330	Dryer pump zone 2	1	0.55	1.5
M390	Dryer humidity extraction	1	2.2	4.8
M391	Connecting unit humidity extraction	1	0.75	1.8
M401A-M402D	Cooler ventilation units	8	1.1	2.6
M614	Stripper	1	0.37	1.1
M615	Belt	1	0.75	1.85
M617	Cutting disc	1	2.2	4.8
M625	Dust blower	1	0.25	0.72
M101-M200	From mixer to pre-dryer	27	139.5	-
		Total =122	Total= 231.22kW	

Appendix F: Rated power and current of electrical motors of plant-4

Electrical motors function area	**Quantity**	**Rated power [kW]**	**Rated current[A]**
Vacuum pump	1	7.5	14.65
Water Doser	1	0.55	1.47
Flour Doser	1	0.75	1.85
Screw	1	0.18	0.57
Pre mixer	1	1.5	4.24
Mixer	1	9.2	19
Compression screw	1	60	110
Hydraulic pump	1	2.2	4.8
Die lifting hoist	1	0.55	1.47
Head ventilation	1	3	6.1
Control temperature cylinder - head	1	5	7.6
Control temperature cylinder - head	1	0.55	1.47
Cutter	1	3	6.4
Shaker movement	1	1.5	3.6
Shaker ventilation	4	4	8.2
Shaker humidity extraction	1	1.1	2.6
Dryer loading elevator	1	0.75	1.85
Dryer loading vibrator	2	0.525	0.92
Dryer movement tier 1-3-5	1	0.37	2.94
Dryer movement tier 2-4-6	1	0.37	2.94
Dryer movement tier 7	1	0.25	1.47
Dryer movement tier 8	1	0.25	1.47
Dryer movement tier 9	1	0.25	1.47
Dryer ventilation charge	1	1.5	3.3
Dryer ventilation zone A1	12	1.5	3.4
Dryer pump zone A1	1	2.2	4.8
Dryer ventilation zone A2	6	1.5	3.4
Dryer pump zone A2	1	0.55	1.47

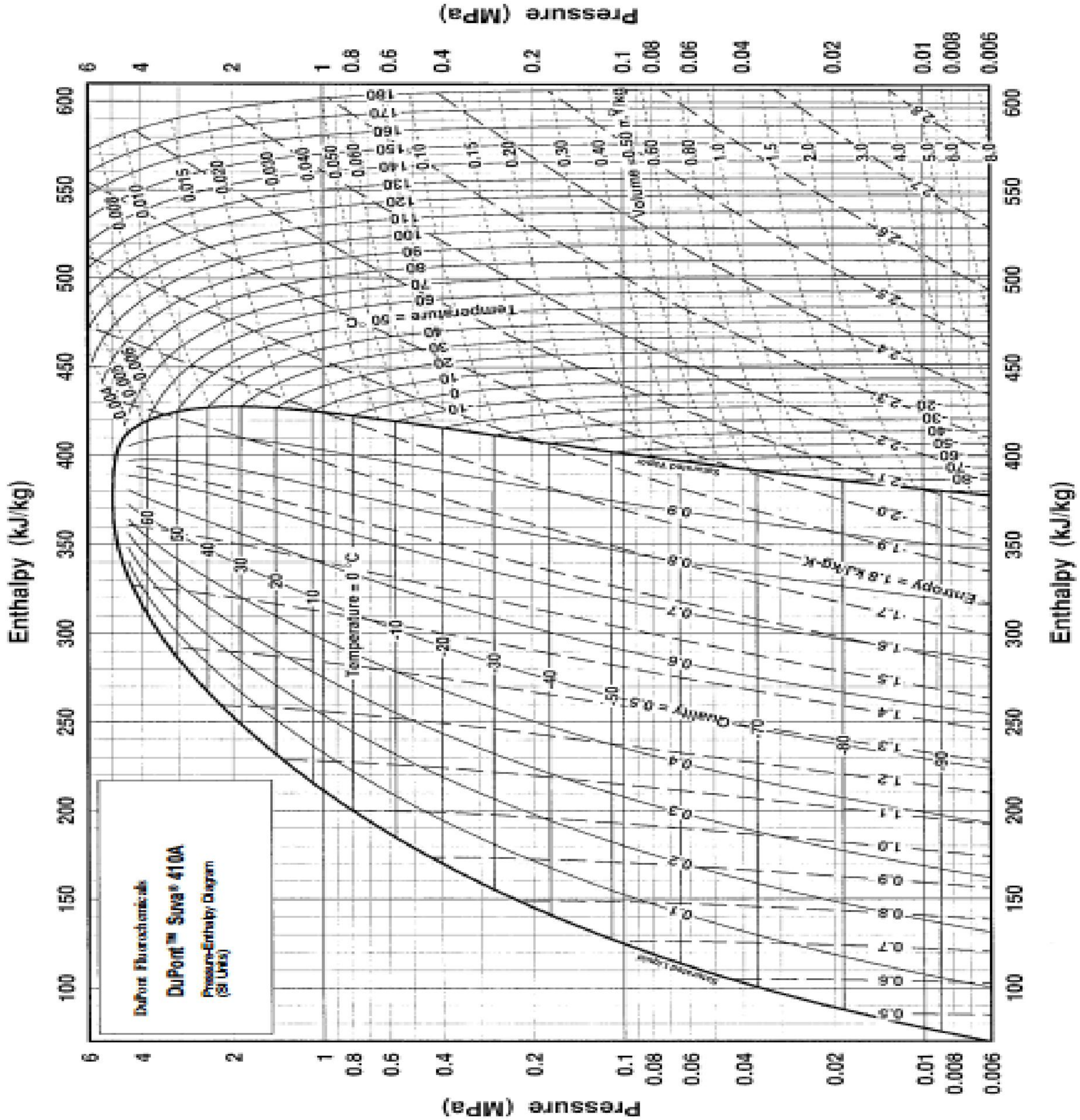
Dryer ventilation zone S	6	1.5	3.4
Cooling zone S	2	0.55	1.47
Dryer pump zone S	1	0.55	1.47
Dryer humidity extraction	1	3	6.1
Dryer ventilation discharge	1	0.55	1.7
Compressor zone A1	1	0.25	0.72
Compressor zone A2	1	0.25	0.72
Cooler movement	1	0.18	0.72
Cooler ventilation	6	0.55	1.47
Sifter vibrator	1	0.75	1.85
Elevator belt charge	1	0.75	1.85
	Total=71	Total = 166.8kW	

Appendix G: 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 H: Refrigerant R-410A Property



Appendix I: Refrigerants' R - 407C property Chart