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MSc Thesis

Feasibility Study of Replacement of Electric Steam Boiler by Wood Biomass Boiler and Old Electric Motors in Ethiopian Pulp and Paper Share Company

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfilment of the Degree of Master of Science in Thermal Engineering

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DEDICATION

I dedicate this thesis to the loving memory of my mother

Enanu Geremew Hailu

You have successfully made me the person I am becoming

You will always be remembered

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ACKNOWLEDGEMENTS

First and foremost, I am highly grateful to the Almighty God for His blessing that continue to flow into my life, and because of You, I made this thesis effectively through against all odds.

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Alem Tafesse

25 October 2016, Addis Ababa, Ethiopia.

ABSTRACT

Energy is essential for the functioning of most of the industrialized world as well as developing and under-developed nations. Yet, at the same time, energy production and consumption causes degradation of the environment of the industrialized world and it seems that developing countries are also facing the similar kind of problem. Therefore, the managing of energy is always required everywhere in the world. Energy management is critical to our future economic prosperity and environmental well-being and it is one of the most critical issues for the future as so much of the world is dependent upon it.

From the country-wise paper & paperboard production and consumption statistics, currently the annual total paper and paperboard production in Ethiopia is nearly 8,000 tons. The annual net consumption of paper in Ethiopia is 400,000 tons and the per capita consumption of paper in Ethiopia is 4 kg/year/person. However, the average per capita consumption of paper in the world is 57 kg/year/person. Consequently, the per capita consumption of paper in Ethiopia is among the lowest in the world today. By the way, the purpose of this thesis is not to focus on the amount of paper production and steam consumption. That is only on the amount of energy consumption and its cost. Moreover, it is also to focus on the ways how to minimize the cost of energy consumption and to increase the efficiencies of the energy consumption of the highly energy utilized devices.

It is well-known that pulp and paper industry is highly energy intensive. Out of the total energy requirement of the paper and paperboard production in EPPSC, 81.69 % energy is used as process heat and 18.31 % as electric energy. Its energy requirement is estimated to increase further in the years to come. At present, its total energy consumption varies from 2,951.30 to 4,995.44 kWh/ton of paper. Notwithstanding, total energy consumption in paper manufacturing companies in developed countries varies from 1,450.00 to 1,650.00 kWh/ton of paper. Source: UNIDO (2010): Global Industrial Energy Efficiency Benchmarking. November 2010. Therefore, the EPPSC consumes very high amount of energy compared with the international standards for energy consumption to produce paper. In addition to this, the boiler used for paper production in EPPSC is electric steam boiler which is not economically acceptable everywhere in the world and the highly energy utilized motors were bought before 50 years.

In view of energy scenario, the need for energy management and conservation, in EPPSC, is strongly felt. Thus, the study aims at various measures and means which can be applied in EPPSC for energy management.

Taking into account the above facts, the main purpose of the thesis is to study the energy consumption pattern of the various processes involved in the EPPSC and to find out possible means and ways through which the consumption and cost of energy can be improved, which in turn will help in development and competitive edge of the company.

On this thesis the following most basic results are obtained:

Economic Benefits:

- Net annual savings of 3,894,255.57 Birr (179,541.52 USD) by changing the electric steam boiler with wood biomass boiler. For this investment, the payback period is 5.28 years.
- Net annual savings of 512,365.20 Birr (23,622.19 USD) by changing the three very old motors with the new motors having equivalent nameplate data. For this investment, the payback period is 5.20 years.
- Total Net Annual Savings is equal to 4,406,620.77 Birr (203,163.71 USD).

From EPPSC, it is obtained that the annual profit is nearly 3.8 Million Birr (175,195.94 USD) for the annual turnover of 68 Million Birr (3,135,085.29 USD) and the annual production of 450,000 ton. Thus, the annual profit will increase by 116 % on condition that the recommended investment is implemented in the company based on the result of this thesis.

Environment Benefits on using wood biomass boiler:

- Ratio of CO_2 generation = 0.433 kg/kWh. The benchmark value for the ratio of CO_2 generation = 0.390 kg/kWh. Thus, the result is almost acceptable.
- SO_2 emission per hour at standard conditions = 155 mg/m^3. The European emission standard for $SO_2 \leq 200$ mg/m^3. Thus, the result is acceptable.

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ABBREVIATIONS

A.C.	Alternate Current
ACIMs	A.C. Induction Motors
AOMC	Annual Operational and Maintenance Cost
D.C.	Direct Current
ECCP	European Climate Change Program
EECA	Energy Efficiency and Conservation Authority
EEPCo	Ethiopian Electric Power Corporation
EN	European standards for products and services by European Committee for Standardization
EPPSC	Ethiopian Pulp and Paper Share Company
EREDPC	Ethiopian Rural Energy Development and Promotion Center
EU	European Union
FOB	Free On Board
GHG	Green House Gas
HHV	Higher Heating Value
HHV_d	Higher heating value of the biomass in bone dry biomass
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISO	International Organization for Standardization
LHV	Lower Heating Value
NEMA	National Electrical Manufacturers Association (in America)
NPV	Net Present Value
OTA	Office of Technology Assessment
PBP	Payback Periods in years
PCBs	Polychlorinated biphenyls
PDCA	Plan-Do-Check-Act
PF	Power Factor
PI	Profitability Index
PRM	Revolutions Per Minute

PV	Present Value
UNEP	United Nations Environmental Program
UNIDO	United Nations Industrial Development Organization
URL	Uniform Resource Locator, internet address
USD	United States Dollar
VSD	Variable Speed Drive
WBISPP	Woody Biomass Inventory and Strategic Planning Project

SYMBOLS

_	Minus sign
+	Plus sign
±	Plus or minus sign
=	Equality sign
≈	Approximation sign
↔	Equivalent sign
×	Multiplication sign
÷	Division sign
≥	Greater than or equal to sign
≤	Less than or equal to sign
>	Greater than sign
/	Per
“ “	Quotation mark
?	Question mark sign
@	At
etc	And other things or and so forth
&	And
π	Pi
vs	Versus
№	Number sign
%	Percentage

% Error	Percentage error
ton	Metric ton
m	Meter
cm	Centimeter
µm	Micrometer
ft	Foot
Lt	Liter
m^3	Cubic meter
m^2	Square meter
kg	Kilogram
$\dot{m}$	Mass flow rate
kg/s	Kilograms per second
kg/h	Kilograms per hour
ton/h	Short ton per hour
kg/min	Kilograms per minute
m^3/h	Cubic meters per hour
gm/h	Grams per hour
rad/s	Radian per second
kg/m^3	Kilograms per cubic meter
mg/m^3	Milligram per cubic meter
gsm	Grams per square meter (g/m^2)
kJ/kg	Kilojoules per kilogram
MJ/kg	Megajoules per kilogram
gm/mol	Grams per mole
hp	Horsepower
kW	Kilowatt
MW	Megawatt
kWh	Kilowatt-hour
kN.m	Kilonewton-meter
V	Voltage or electric potential difference

I	Electric current
R	Electric resistance
kAmps	Kiloamperes
Hz	Hertz
P	Pressure
kPa	Kilopascal
MPa	Megapascal
bar	Metric unit of pressure, but not part of the International System of Units (SI)
T	Temperature
^{0}C	Degree centigrade
η	Efficiency
h	Specific enthalpy
X	Mass fractions (percent mass dry basis)
n_n	Mole fractions of components
C	Carbon atom
H	Hydrogen atom
S	Sulfur atom
N	Nitrogen atom
O	Oxygen atom
Ash	Ash content
MC	Moisture content
O_2	Oxygen molecule
CO_2	Carbon dioxide molecule
H_2O	Water molecule
SO_2	Sulfur dioxide molecule
N_2	Nitrogen molecule
α	Stoichiometric air-fuel ratio
λ	Excess air ratio
Z	Compressibility factor
$R_{Specific}$	Specific gas constant
R_U	Universal gas constant = 8.315 J/kmol

M	Molar mass of gas
kg/kWh	Ratio of CO_2 generation
q_{CO_2}	Specific CO_2 emission (CO_2/kWh)
C_f	Specific carbon content in the fuel (kg C/kg Fuel)
h_f	Specific energy content (kWh/kg Fuel) = LHV
C_{CO_2}	Specific mass of Carbon dioxide (kg/mol CO_2)
C_m	Specific mass of Carbon (kg/mol Carbon)
Ø3	Three phase
Ω	Rotational speed of shaft of motor
S_S	Synchronous speed
S_r	Nameplate full-load speed
V_r	Nameplate rated voltage
P_i	Three-phase power in kW
P_{ir}	Three-phase power in kW
P_{input}	Input power to motor
P_{output}	Output power of shaft of motor
P_{rated}	Nameplate rated power
τ_{output}	Output torque of shaft of motor
τ_{rated}	Nameplate rated torque
Ω_{rated}	Nameplate rated rotational speed (in rad/s)
Load	Percentage loading
η_{FL}	Efficiency at full rated load
Birr	The unit of currency in Ethiopia
Million Birr	10^6 Birr
Birr/year	Birr per year
Birr/m^2	Birr per square meter
S	Salvage value
P	Original price
Y	Age in years
i	Nominal depreciation rate

i	Real interest rate
r	Nominal interest rate (discount rate)
p	Inflation rate
C_t	Net annual savings
V^t	Present value factor
S	Net annual savings cost
H	Annual operating time
C	Cost of electrical energy per kWh
CD	Cost difference between the recommended motors investment & the old motors investment

CHAPTER 1: INTRODUCTION

1.1.Overview

Energy is essential for the functioning of most of the industrialized world as well as developing and under-developed nations. Yet, at the same time, energy production and consumption causes degradation of the environment of the industrialized world and it seems that developing countries are also facing the similar kind of problem. Therefore, the managing of energy is always required everywhere in the world. Energy management is critical to our future economic prosperity and environmental well-being and it is one of the most critical issues for the future as so much of the world is dependent upon it.

Energy requirement is a quantitative measure of the total energy required for the manufacture of a product, including the energy used in converting materials, providing heating for the process, transporting, lighting and so on; typically having units of mega joules per ton of product. Since it is related only to the number of energy units used in the manufacture of a particular mass of product, it can be used to make judgment about the energy efficiency with which a product is made (Barratt, 1996, p. 616).

From the country-wise paper & paperboard production and consumption statistics, currently the annual total paper and paperboard production in Ethiopia is nearly 8,000 tons. The annual net consumption of paper in Ethiopia is 400,000 tons and the per capita consumption of paper in Ethiopia is 4 kg/year/person. However, the average per capita consumption of paper in the world is 57 kg/year/person. Consequently, the per capita consumption of paper in Ethiopia is among the lowest in the world today.

By the way, the purpose of this thesis is not to focus on the amount of paper production and steam consumption. That is only on the amount of energy consumption and its cost. Moreover, it is also to focus on the ways how to minimize the cost of energy consumption and to increase the efficiencies of the energy consumption of the highly energy utilized devices.

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Notwithstanding, total energy consumption in paper manufacturing companies in developed countries varies from 1,450.00 to 1,650.00 kWh/ton of paper. Source: UNIDO (2010): Global Industrial Energy Efficiency Benchmarking. November 2010.

Therefore, the EPPSC consumes very high amount of energy compared with the international standards for energy consumption to produce paper. In addition to this, the boiler used for paper production in EPPSC is electric steam boiler which is not economically acceptable everywhere in the world and the highly energy utilized motors were bought before 50 years.

1.2. Purpose

In practice, paper production industry is a very energy intensive. EPPSC has been under tremendous economic pressures in the last many years because of the high consumption of electric energy and the very high expense for this electric energy consumption. As a result, it is essential to use sustainable energy management as a tool in the company. Therefore, the main purpose of the thesis is to study the ways to minimize the cost of energy consumption and to increase the efficiencies of the electric energy consumption of the highly energy utilized equipment, which in turn will help in development and competitive edge of the company.

1.3. Objectives

1.3.1. General Objective

The general objective of the study is to increase the energy utilization efficiency in the EPPSC by reducing the cost of energy and energy lost due to poor performance of basic equipment.

1.3.2. Specific Objective

As the energy management is a comprehensive subject, it is not possible to consider every aspect of it. In order to limit the study, the following objectives are considered for this thesis:

1. Studying the energy requirement in various processes of paper manufacturing in EPPSC.
2. Evaluating of the economic advantages and disadvantages of using electric steam boiler and very old electric motors for paper manufacturing in EPPSC.
3. Finding out the economic choice, without affecting the environment, to reduce the cost of electric energy consumption without affecting the paper manufacturing processes.
4. Reducing the production cost of the paper and paperboard by adopting the minimization of the cost of energy.

1.4.Potential Significance

The energy consumption of EPPSC is being under tremendous economic pressures in the last so many years. Being economically competitive in the national and global market place and meeting increasing environmental standards to reduce air and water pollution have been the major driving factors in most of the recent operational cost and capital investment decisions of the company. So in order to meet the critical objectives for short-term survival and long-term success, energy management can be used as a tool in the company.

By this study, scientific and mathematical data analysis are carried out to replace highly energy consuming equipment such as boiler and motors in order to minimize the cost of energy consumption and to increase the net annual profit of the company.

1.5.Research Problems

This thesis gives scientifically and mathematically acceptable responses for the following three most basic research questions:

1. Is electric steam boiler an economic choice?
2. Is wood biomass boiler environmentally friendly and economic choice?
3. Is very old electric motor having high horsepower capacity economically acceptable to be used for manufacturing?

1.6.Limitations

The main purpose of the study is to understand the concepts of energy management and its implementation. The area of energy management is very vast and within the limitations of time and resources, it will not be possible to discuss all the aspects in the study.

Most of the analysis for the study will be carried out from secondary data collected from a number of sources. There will be limitations in obtaining latest and current data for quite a few cases and projections will be used from the past trends to arrive at certain figures.

1.7.Thesis Organization

The thesis has been presented in seven chapters. In the first chapter, which is the present one, a brief overview has been given. The purpose, objectives, potential significance and statement of the problem are presented. Chapter two provides literature review on energy security, industrial energy use and management, and energy audit. In chapter three, the concepts on paper making process in the EPPSC have been discussed in detail. In chapter four, instruments and methodology used for this thesis are described briefly. In chapter five, the data analysis for energy audit based on the data collected from EPPSC is carried out in detail. In chapter six, result and discussion are presented based on the outcomes of the data analysis for energy audit. In chapter seven, conclusion and recommendation are provided. Finally, appendix and references are listed.

CHAPTER 2: LITERATURE REVIEW

2.1.Energy Security

In the last few decades, debates on sustainable development have been a high profile topic amongst policy makers and researchers worldwide; in the advent of rapid global economic and industrial growth, issues of energy use have also gained high attention in the same respect. Since energy is an essential input for every nation; and it plays a vital role in the economy and security of any nation (Pode, 2010). Energy security is topical in the debate of developing a sustainable energy system. This concept describes the ability to supply or utilize energy in a manner that is reliable, affordable, accessible and environmentally friendly.

The world bank group defines energy security more broadly as the means of a country to produce and use energy in a sustainable manner and at a reasonable cost in order to facilitate economic growth and, through this, poverty reduction and directly to improve the quality of peoples‘ lives by broadening access to modern energy services (World Bank Group, 2005). However, it is important to note that, notion of energy security frequently differ by personal and institutional perspectives, national styles, geology, geography, and time (Sovacool & Brown, 2010). This has resulted in diversity of definitions and perceptions, for instance the world bank definition of energy security is based on three pillars that is energy efficiency, diversification of supply, and minimization of price volatility (World Bank Group, 2005). From end users‘ perspective, energy security entails the supply of energy service without disruptions (Sovacool & Brown, 2010). For energy producers, it is the ability to secure long term and attractive markets for their natural resources that often under pin their economies (World Bank Group, 2005). In general, energy security consists of four interconnected criteria or dimensions: availability, affordability, efficiency, and environmental stewardship (Sovacool & Brown, 2009).

Availability dimension of energy security refers to procuring sufficient amount of energy to ensure uninterrupted supply and reduce foreign dependency on fuel (Sovacool & Brown, 2010). Availability in part also involves the diversification of energy service that can help in reducing energy security risk of individual. Diversification encompasses three dimensions namely:

- Source diversification requires utilizing a mix of different energy sources, fuel types, and fuel cycles.
- Supplier diversification refers to developing multiple points of energy production so that no single company or provider has control over the market.
- Spatial diversification means dispersing the locations of individual facilities so that they cannot be disrupted by a single attack, event, malfunction or failure.

Access to affordable and equitable energy supply is an important aspect of any country‘s energy security. Basically, the affordability dimension defines the provision of energy and energy services at a price that is affordable to all citizens in a country. Volatile energy prices can disrupt the energy security of a country; therefore, energy fuels and services must not only be affordable, but their prices should be stable (Sovacool & Brown, 2010).

Efficiency is a cost effective means of ensuring energy security by minimizing the unit resource input per unit output. Efficiency can be subdivided into parts namely economic and energy efficiency. In the economic sense, efficiency is the measure of the improvement of performance or increased deployment of more energy efficiency equipment and conservation (Sovacool & Brown, 2010). But, energy efficiency refers to improving the performance of energy equipment and altering consumer attitudes (Sovacool & Brown, 2009).

In recent years, the growing interest and consciousness of environmental protection is a major boost for issue of energy security; stakeholders worldwide are trying to find innovative means to protect the environment by minimizing energy consumption from carbon intensive and non-renewable sources.

The environmental stewardship emphasizes the importance of environmental sustainability, which consists of protecting the natural environment, communities and future generations (Sovacool & Brown, 2010; Sovacool & Brown, 2009).

2.2. Industrial Energy Use: a key Promoter of Sustainable Industrial Development

The quest to attain sustainable industrial development is one of the greatest challenges of the 21st century. Besides the fact that industrialization has brought unprecedented improvement of wealth and prosperity, industrialization has also produced many externalities like the over exploitation of natural resources, air and water pollution, climate change and massive accumulation of waste on the earth surface. In recognition of the earth's limited capacity, researchers posit that industrial development must progress in a sustainable direction to insure that the needs of this generation are met without compromising the ability of future generations (UNIDO, 2011); this involves taking into consideration environmental protection, social advancement and economic development. The exploitation and harnessing of primary energy sources for industrial purposes is one of the major threats of industrial development; therefore, the progressive development of industrialization is vitally dependent on industrial energy use.

The industrial sector uses more energy than any other end-use sectors and this sector represents about 37 % of the world‘s primary energy consumption (Abdelaziz, Saidur & Mekhilef, 2011); also industrial energy consumption is projected to grow at 2.4-3.2 % per year through 2030 in developing countries and 1.2 % in developed countries (UNEP,2007).

For industries to operate in a sustainable manner, it is then required that innovative mechanisms should be tailored to solve the negative impacts of industrial energy use particularly climate change. Industrial energy efficiency and management are effective means of mitigating the negative effects of industrial energy consumption and at the same time ensuring the improvement of both productivity and competitiveness of industries. In line with increasing industrial energy efficiency, industries need to switch energy sources (especially from carbon intensive sources) so that operations use the most suitable energy source, which can reduce environmental impacts of energy use (UNIDO, 2011). Energy efficiency standards for industrial motors have proven to be one of the most cost-effective methods of increasing energy efficiency in industries. The harnessing of low-grade heat from processes in industries is another means of increasing the overall energy efficiency significantly (UNEP, 2007).

Improving energy efficiency goes beyond the efforts of individual industries; it also involves the active participation of governments and policy makers. Governments are responsible for enforcing market-based measures such as taxes and fees to encourage energy conservation; strict pollution policies; subsidies to stimulate cleaner technologies development and adoption.

2.3. Industrial Energy Management

Numerous studies conducted in the field of industrial energy efficiency show that there are tremendous saving potentials that can be achieved through the effective implementation of energy management in industries. A study by Caffal (1996) revealed that industrial energy management has the potential of saving about 40 % of energy use in an industrial facility. Between the periods of 1990-2009 Dow Chemical, reduced its energy intensity by 38 % by implementing an energy management system, which corresponding to an energy saving of 1,700 trillion Btu (Dow, 2012). Toyota North American Energy Management Organization also reduced energy use per unit by 23 % since 2002 by applying an energy management system (Scheihing, 2009). However, the viability of such industrial energy saving potentials are dependent on a variety of factors like technical, economical, institutional and political (OTA, 1993); consequently, these factors are either directly or indirectly related to the energy management of an industrial facility.

Energy use in industries is more dependent on operational practices (specifically energy culture of the industrial facility) than in the commercial and residential sectors (McKane Williams, Perry & Li, 2007). As such, most industrial energy efficiency improvements are achieved through changes in how energy is managed (or used) in the facility, rather than through installation of new technologies (McKane, 2009). Accordingly, it is then evident why upgrading the efficiency of technologies alone cannot achieve optimal savings, but when combined with operational and maintenance practices as well as management systems can lead to significant savings (Scheihing, 2009).

The implementation of energy management system in facility provides an enabling environment to identify opportunities for and to realize energy savings in a sustainable manner (Worrell, 2009); and also provides industries with the opportunity of integrating energy efficiency practices to suit existing management systems. Consequently, energy management is a key lever to realizing sustainable industrial energy efficiency worldwide. Currently, there exist new international energy management standards like the ISO 50001 and EN16001 which are designed to be suitable for energy management in all types and size of businesses across the worldwide.

2.3.1. Effective Features of Energy Management Systems

The purpose of an energy management standard is to provide guidance for industrial facilities to integrate energy efficiency into their management practices, including aligning production processes and improving the energy efficiency of industrial systems (McKane, Price and Rue du Can, 2008). Specifically, an energy management standard offers an expert and best practices framework for organizations and enterprises to develop energy efficiency goals, plan interventions, prioritize efficiency measures and investments, monitor and document results and ensure continuity and constant improvement of energy performance (UNIDO, 2008).

Most management standards (including energy management systems) are designed based on Plan-Do-Check-Act (PDCA) model, which fosters an organizational culture of continuous improvement in energy efficiency. The culture of continuous improvement is achieved in a gradual and continuous manner; in addition, it ensures the setting of goals that are realistic, achievable and suits the resources (personnel, economic and technical) available to the firm.

2.3.1.1. Plan Phase

One key requirement of an energy management standard is the establishment of an energy policy, which entails the energy plan, goals, commitments, targets and procedures of the top management; the energy management plan is implemented through an energy management program. McKane et al (2008) states “In companies without a plan in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers”. Therefore, the formulation of an energy plan and its implementation through an organizational-wide energy program is a cost effective means of overcoming energy efficiency barriers and improving energy efficiency.

Energy audit is an important feature of an energy management systems; an audit is carried out to gather relevant historical data concerning energy consumption trends. An energy audit is conducted at the beginning of a program to establish both the present and past energy consumption of the facility; based on these data energy hotspots can be identified and benchmarks can be drawn for evaluating improvements. Energy audits are also conducted to assess the level of progress of ongoing programs.

2.3.1.2. Do Phase

This phase involves the implementation of the energy management program by aligning operation and activities of the firm to reduce energy use of equipment systems and processes. A successful energy management program begins with a strong organizational commitment to continuous improvement of energy efficiency (Worrell, 2009); therefore, an energy management program involves the assigning of management duties and the creation of a cross-functional energy committee in the plan phase. The responsibility of the committee is to steer and monitor the program and ensure the continuous improvement of goals; the motivation of worker (personnel) by top management is an effective means of involving company personnel with diverse expertise into the energy management program. The first step in an energy management program involves the training of the committee and workers of the firm at large. This is done to build the needed energy management competence and to inform workers. The creation of documentation like an energy manual is an effective means of communicating and educating working personnel of the energy program.

2.3.1.3. Check Phase

This phase aims at monitoring and measuring the performance (by conducting energy audits) in terms of energy saving and comparing objectives and set targets. If there are any shortfalls, it is then necessary that the causes are identified and analyzed to make corrections in order to realize the setting goals. Thus, it is important that the setting goals should be quantifiable to facilitate the assessment of progress and improvements.

2.3.1.4. Act Phase

This phase basically involves management reviews of audit, internal and external reports pertaining to the performance of the energy management program. These reports play an important role for the organization to identify shortfalls and other missed hotspots to act upon them to ensure continual improvement.

2.4. Industrial Energy Audit

Energy audit 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. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management program.

Industrial energy audit may be divided into three main parts:

1. Energy Survey
2. Energy Analysis
3. Suggested Measures

2.4.1. Energy Survey

This part gives responses for the following request:

What do we have?

- Define the system boundary.
- Identify unit processes.
- Quantify energy supply.
- Allocate energy use to different unit processes.

2.4.2. Energy Analysis

This part gives responses for the following requests:

How "bad" is the utilization of the supplied energy?

Where does it go wrong?

How far can we reach?

- Identify both system errors and detail problems.
- Identify idling power and energy.
- Identify mismatching energy quality, where high quality energy is used non-demanding purposes.
- Identifying barriers and driving forces.
- Sum up the potential for energy efficiency and conversion for the system as a whole.

2.4.3. Suggested Measures

This part gives response for the following request:

What can we do about it?

- Identify possible solutions.
- Calculate the impact of the solutions and analyze them.
- Calculate the economic impact.

Source: Jakob Rosenquist, Patrik Thollander and Patrik Rohdin (2012): Industrial Energy Auditing for Increased Sustainability-Methodology and Measurements.

CHAPTER 3: PAPER MAKING PROCESS

3.1.Introduction

Paper production in this company starts from importing the processed pulp from other countries that means the production of pulp in the country is not there until present day.

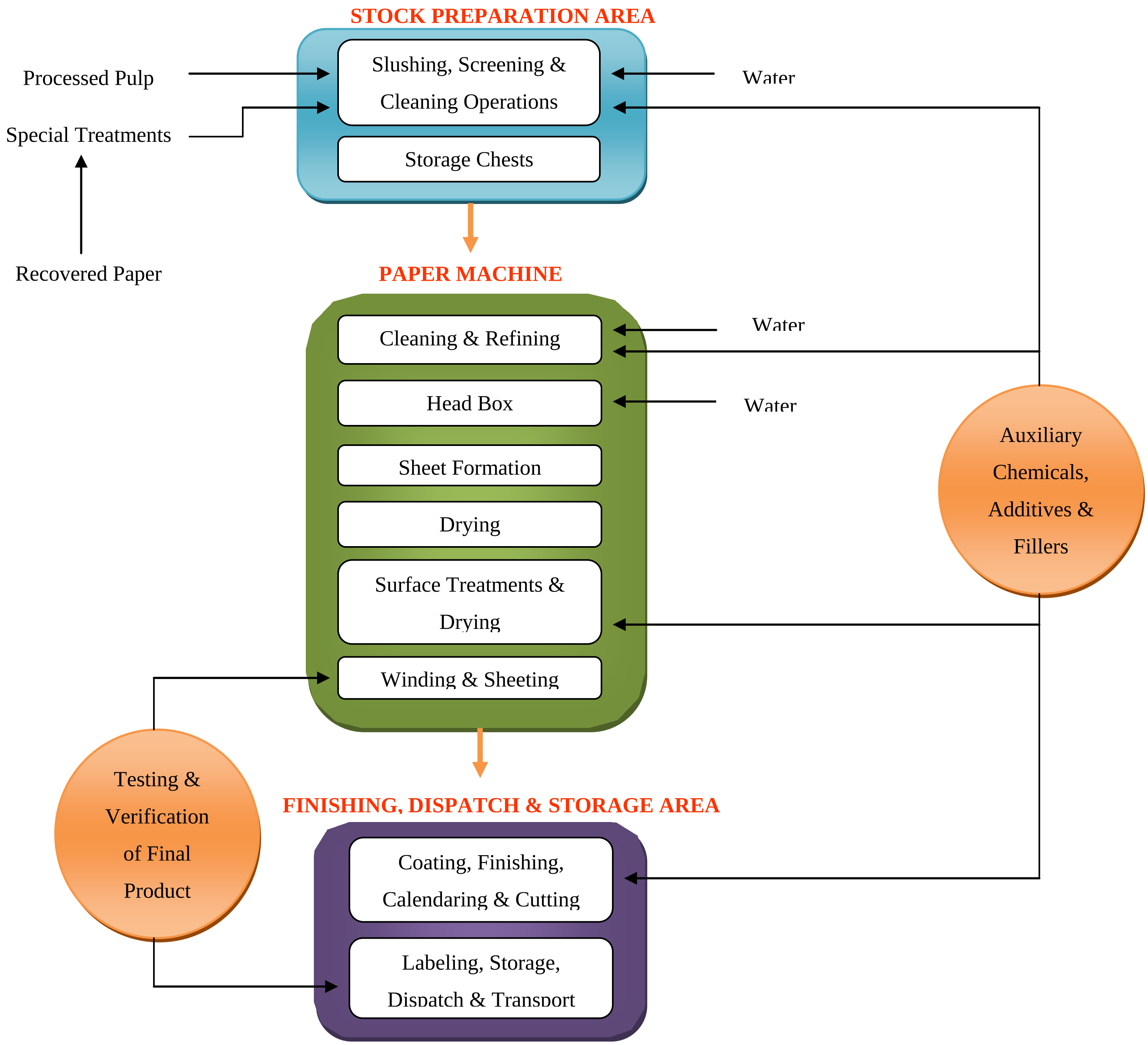


Figure 3.1: Schematic Diagram of Paper Production Process

The pulp is received in the form of pressed sheets which have to be broken down in water so that the pulp is suitable for use. The operation of breaking down the pulp, or cutting, to separate the fibers is carried out in the machine known as hydra-pulper where the fibers must be subjected to a series of operation to alter them thus to provide the properties required for obtaining a certain type of paper. The production starts by hydra-pulping of the raw materials (furnishes) with sequences of sub- process.

The company's paper machine is mainly composed of sheet forming section, pressing section, drying section and calendar/reel section.

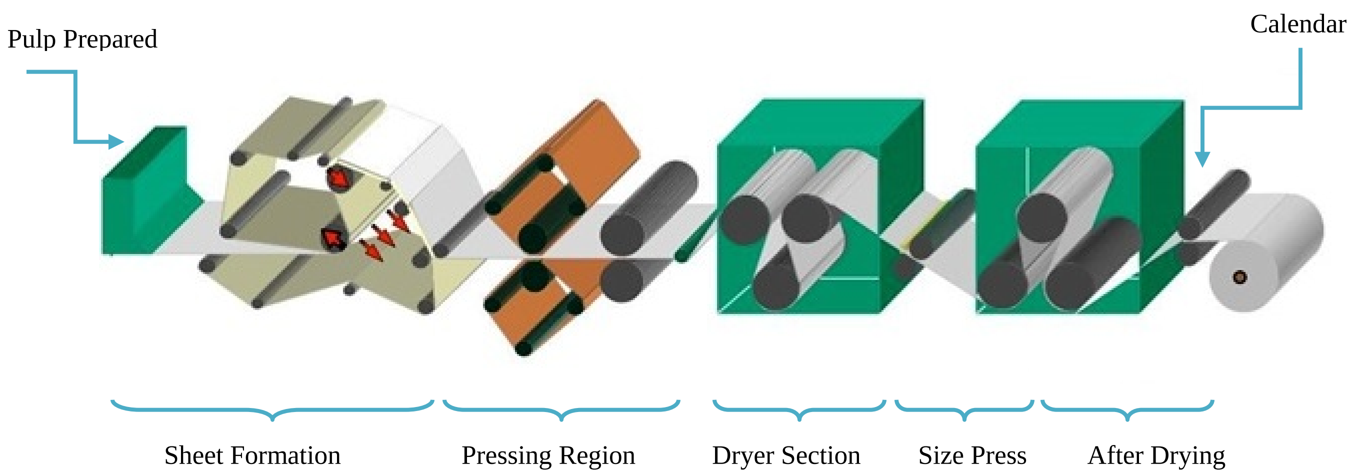


Figure 3.2: Model of the Mechanism of Paper Machine

Once the pulp has been provided with the necessary properties and the mixture of raw materials has been correctly prepared (fibers, additives, etc) in the mixing box, the processing stages in the paper production continue.

Formation of the sheet will be carried out which will be the sheet of the paper. Sheet formation is the inter link of fibers with one another with the help of a series of dewatering elements, the water in the sheet is eliminated. The drying operation is used immediately after the formation of sheet. When the paper comes out of the press section, its water content is usually about 60 %. Drying operation takes on after sheet operation where by the moisture of the paper will be reduced to 5 % water, which is the content that it must have at the end of the manufacturing process. The drying operation is the process where energy transfer (heat is applied to the sheet) and a mass transfer (steam transferred into the atmosphere) occur.

Then after drying comes, a calendaring operation which generally improves the gloss and printing properties of paper, which has a series rolls positioned on top of the other, which during its roll give the paper its gloss. More defects are observed in calendaring

The most common types of paper products in the company are papers and paperboards in the 45 to 350 gsm weight ranges.

3.2.Raw Materials for Paper Production

Raw materials used for the production of both paper and corrugated box are listed as follows:

- Virgin Pulp
- New Cut Corrugation
- Local Corrugation Broke
- Mixed Broke
- Old Cut Corrugation
- White Broke
- Bleached Hardwood Short Fiber
- Bleached Softwood Long Fiber
- Unbleached Kraft Pulp

3.3.Main Chemical Additives for Paper Production

The followings are the main chemical additives:

1. Size Press Starch
2. Alum or Alum sulphate ($AL_2(SO_4)_3$ X H_2O)
3. Fortified ROSIN (Sizing Agent)
4. China Clay
5. Dyes (Basic, Acidic and Direct Dyes)

1. Size Press Starch

It is the most common surface sizing materials. It is believed that its primary functions are to improve bonding at the surface, to plug the surface & to retain penetration of water.

2. Alum or Alum sulphate ($AL_2(SO_4)_3$ X H_2O)

It is correctly applied only to designate the double salt of Aluminum sulphate & Alkali sulphate eg. $K_2SO_4.Al_2(SO_4)_3.24H_2O$.

The importance of Alum is for sizing purposes. The actual sizing operation will be minimized.

3. **Fortified ROSIN (Sizing Agent)**

It is the most widely used internal sizing substance in pulp and paper industries. Adding of rosin to pulp stock greatly reduces the absorption of paper to water or water solution.

Rosins are three types:

1. Gum Rosin
2. Wood Rosin
3. Tall Oil Rosin

4. **China Clay (Calcium Carbonate Titanium Dioxide)**

Fillers are inorganic or synthetic pigments which are added into a paper stock to improve the texture & fill the void between the fibers of the paper. Thus, they help to produce a denser, softer, smoother & more opaque sheet. The uses of filler is economically very advantageous, it can substitute 20-30 % of the fiber.

5. **Dyes (Basic, Acidic and Direct Dyes)**

They are substances which by virtue of their chemical construction can import a colored appearance to an object. All dyestuffs or “color acts” can be classified into four main groups:-

1. Natural inorganic dyestuff
2. Synthetic inorganic dyestuff
3. Natural organic dyestuff
4. Synthetic organic dyestuffs

3.4.Main Paper Production Processes

The followings are the four main processes for paper production:

1. Stock Preparation Process
2. Sheet Forming Process
3. Drying Process
4. Calendaring Process

3.4.1. Stock Preparation Process

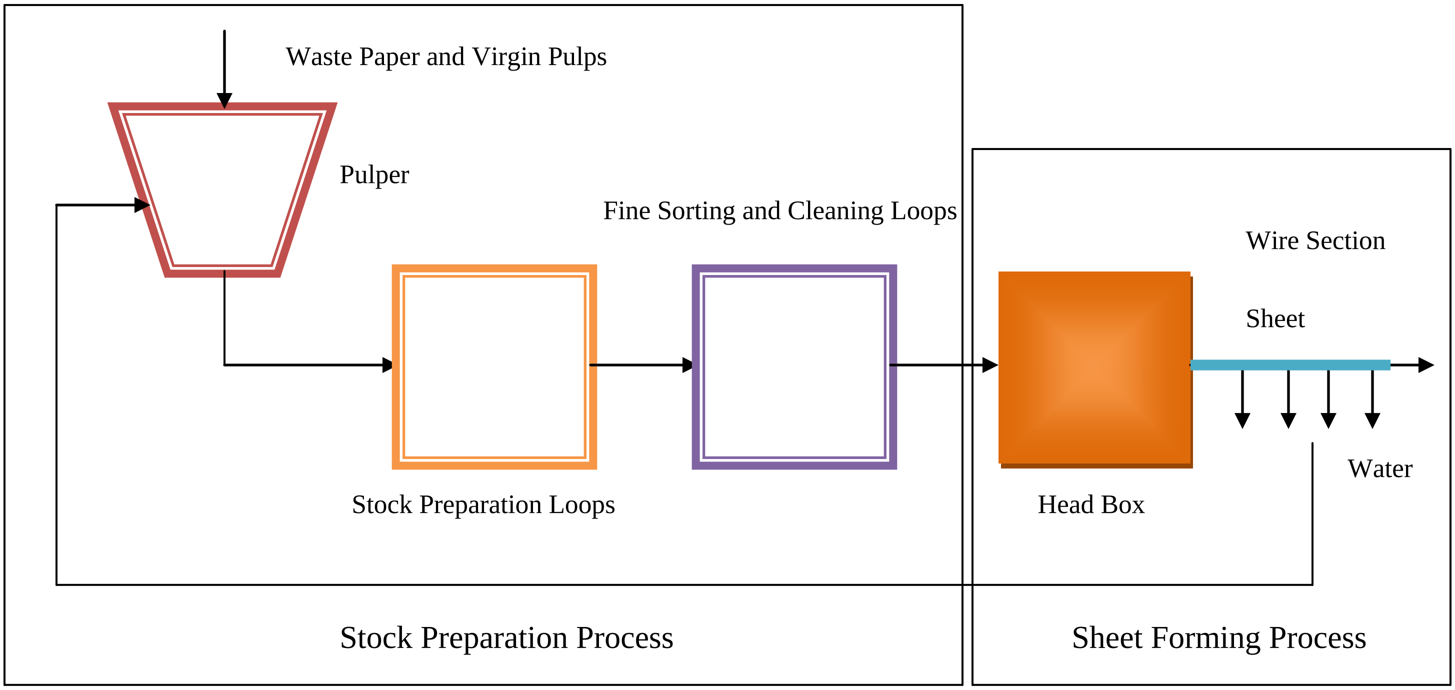


Figure 3.3: Production Scheme of Stock Preparation and Sheet Formation

Once the wood has been reduced to pulp, it is feed to the paper machine for processing. The paper mill (pulper) receives raw materials as rolls, bundles, or pallets of pulp sheets. The raw material usually requires additional refinement and treatment before being used to create the finished paper product.

The objective of fibers preparation system is to modify the different ingoing raw materials in such a way that the finished stock finally supplied to the paper machine that suits the requirement of paper machine and the quality demands put on the produced paper or board.

Stock is prepared as per the furnish sheet requirement where mechanical action is applied (beating in the presence of water) for a defined period of time till the degree of disintegration and water absorption is achieved through checking of the quality parameters like consistency of slashed stock to reach acceptable requirement.

Fibers from recycled papers, wood and cellulose must be treated mechanically and chemically before they are sent to the stock preparation area. Those different fiber and additive streams are combined to one big stream going to the paper machine.

The stocks used are the various types of virgin pulps as well as recovered paper grades. They are available in different forms of bales loose materials. The quality of finished stocks essentially determines the quality of the final paper and paperboard to be produced.

There are four main sub-processes in the stock preparation process. Those are:

a) Pulping Process
b) Blending Process
c) Cleaning Process
d) Refining Process

3.4.1.1. Pulper and Pulping Process

The pulper is a high performance machine in which the disintegration operation is carried out. It is made up of a cylinder shaped recipient, which has a propeller in the bottom part, which shakes up the sheets of pulp that are placed in it. By means of the continuous rubbing of the pulp against the propeller, the fibers which form the bundle of pulp are separated, leaving a suspension in the water with a consistency (percentage of dry material) of between 6 % and 12 %.

3.4.1.2. Refining Process

This is where the cellulose fibers pass through a refining process which is vital in the art of paper making. Any materials used in creating blends must be mixed together for paper making. All the measured raw materials are placed in hydra-pulper or digester with water. The digester disperses the fibers into the water with minimal fiber damage by gentle agitation and heated water. Then the beater breaks down the cellulose fibers into separate fibers. Before refining, the fibers are stiff and inflexible and they form few bonds.

The stock is pumped through conical machines which consist of a series of revolving discs. The violent abrasive and bruising action has the effect of cutting, opening and declustering the fibers and also making the fibers divisible. This process is called fibrillation; hence, the fibers are pliable and have greater surface area which highly improves the fiber bonding. The properties of the paper are directly related to the refining process.

The beating and refining processes are very important in the paper making process. The longer the fibers remain in the beater, the more they become beaten up and the more the surface areas of the fibers are increased.

3.4.2. Sheet Forming Process

There are two main sub-processes in the sheet forming process. These are:

a) Sheet Formation Process
b) Dewatering Process

3.4.2.1. Sheet Formation Process

Sheet forming section is sometimes called as the wet end of the paper machine. This section consists of the head box, the forming wire, foils, suction boxes, couch roller, breast roller and dandy roll. Pulp is pumped from the machine box through the screen and cleaners to the head box. The purpose of the head box is to deliver uniform slurry to the forming wire. The pulp flowing onto the forming wire is approximately 0.5 – 1.0 % fibers with the makeup consisting of water. As the water is removed from the slurry, the fibers settle on the surface of a travelling wire and forming a wet mat of paper; therefore, the main objective of the sheet forming process is the controlled removal of water. The suction boxes remove the majority of the water and change the stock consistency from 2 % to 20 % fiber content.

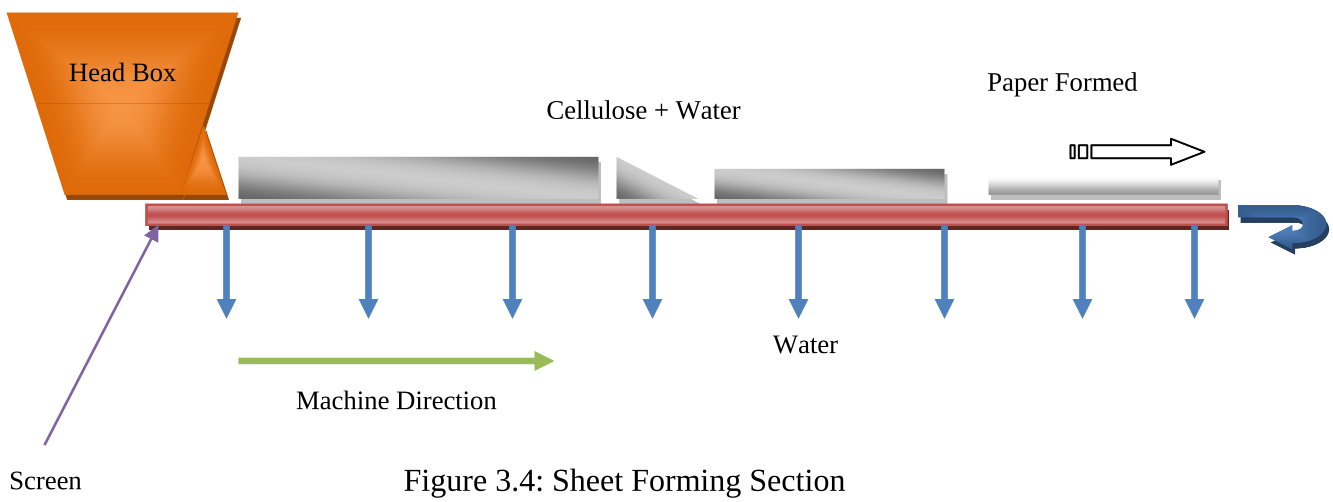


Figure 3.4: Sheet Forming Section

Figure 3.5: Sheet Formation and Dewatering Processes

3.4.2.2. Dewatering Process

Paper slurry consists of around 0.5 – 1.0 % fiber is pumped into a box where it flows out through a slot onto a moving wire belt. Once, on the belt, the water is removed by draining and suction where it leaves the fibers to form a very wet and weak paper. The paper is then pressed, heated, and dried resulting in a continuous roll or web which can be further finished as desired.

The purpose of washing is to remove undesirable particles smaller than 30 µm from the fiber suspension through a separation process; at the same time, dissolved and colloidal contaminants are also removed with filtrate. With the dewatering process, the stock consistency is increased from 5 to 30 % or more to prepare for the next process stage and for complete water loop separation.

3.4.3. Drying Process

This is the process where moisture content is reduced to the desired level. After pressing, the sheet (web) is conveyed through the dryer sections where the residual waters removed by evaporations. Thermal energy, for drying, is transferred to the paper by wrapping a series of large diameter rotating steam filled cylinders.

This is the most expensive part of paper machine in terms of capital cost; moreover, it is the most costly to operate because of the high energy consumption.

Figure 3.6: Drying Room of EPPSC

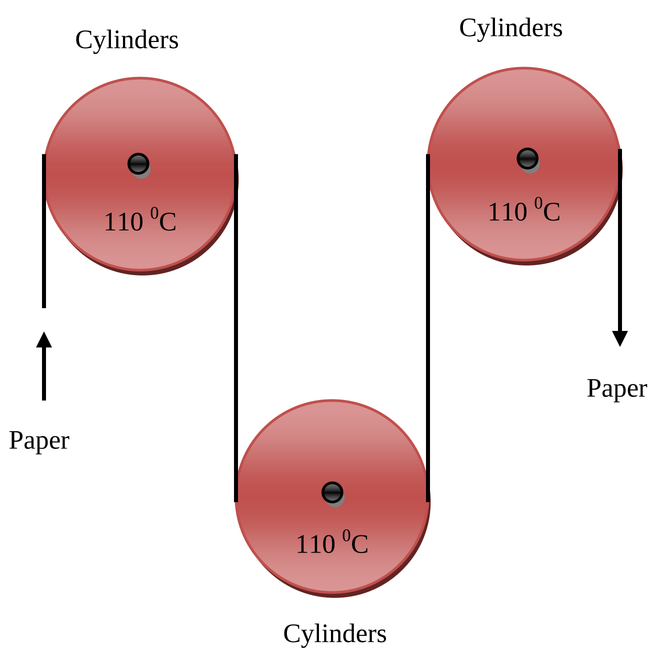


Figure 3.7: Mechanism of Paper Drying Process

The paper drying machine can have three or five groups of drying cylinders. The cylinders are heated by injecting steam internally to permit heating of the surface and drying of the sheet. The temperature of the cylinders can reach 130 ^{0}C.

3.4.3.1. Drying Principles

There are two drying principles. These are:

1. Contact Drying by Steam Heated Cylinders
2. Press Drying

3.4.3.1.1. Contact Drying by Steam Heated Cylinders

With this most common principle in the paper drying,

- steam condenses at the inner surface of the cylinders wall,
- the heat is transferred through the wall to the paper web,
- the web is heated, and
- water is evaporated.

Air flow takes up the evaporated water. The heat transfer rate from the steam to the cylinder shell depends on the flows of pattern of the condensate motion. This flow pattern is mainly dependent on the machine speed and to a lower degree on the amount of condensate volume in the cylinder or on the cylinder diameter. Good heat transfer from cylinders to the paper web is obtained by pressing the web tightly to the cylinder.

3.4.3.1.2. Press Drying

This method is a combination of pressing and drying. First the web is dewatered mechanically in a press nip and brought into tight contact with the hot surface on one side. At the opposite side the web is covered by a permeable belt such as a felt or a wire which continuous top presses the web to the hot surface over a longer distance. The vapor escapes through the permeable cover.

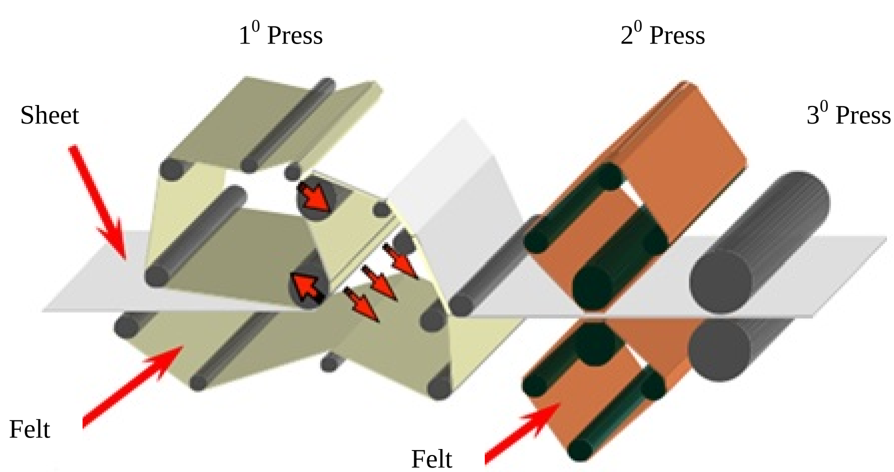


Figure 3.8: Press Drying

The pressing section removes water from the paper sheet with three presses. The first and the second presses are the same, having felt that contacts paper on top and bottom of web. The third press has no felt, only rubber rollers to smooth sheet surfaces.

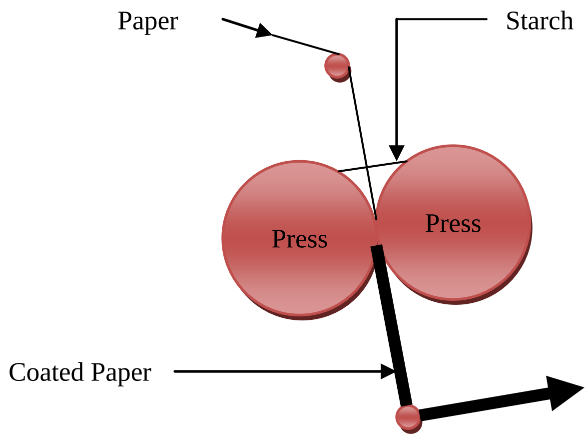


Figure 3.9: Mechanism of Paper Pressing

3.4.4. Calendaring Process

Clearly, the objective in paper calendaring is to control the thickness and surface properties of the paper. In paper manufacturing, calendaring is the process of smoothing the surface of the paper by pressing it between cylindrical rollers at the end of paper making process. Calendars are used to make the paper surface extra smooth and glossy and more uniform thickness.

Figure 3.10: Calendaring Room

CHAPTER 4: INSTRUMENTS AND METHODOLOGY

4.1. Instruments

The following measuring instruments are used to collect different data from the company:

Table 4.1: Instruments used for Measurements

Names	Pictures	Purposes
1. Thermometer		• To measure temperature or temperature gradient.
2. Pressure Gage		• To measure the internal pressure and/or vacuum of a system.
3. Digital Flow Meter		• To measure linear, nonlinear, mass or volumetric flow rate of a liquid or a gas.

4. Digital Voltmeter		• To measure an unknown input voltage by converting the voltage to a digital value and then displays the voltage in numeric form.
5. Digital Ammeter		• To measure the current in a circuit.
6. Digital Power Factor Meter		• To measure the power factor of an A.C. circuit.
7. Power Factor Corrector		• To improve power factor by installing power capacitors.

8. Non-Contact Laser Tachometers	They are used to measure the speed of rotation (RPM) of a shaft by using infrared (laser) light. Sometimes, they are also called as Optical Tachometers.	
a) D.C. Tachometer		• To measure the speed of the shaft of D.C. motor by producing a D.C. voltage.
b) A.C. Tachometer		• To measure the speed of the rotor shaft of A.C. motor by producing an A.C. voltage.

4.2.Methodology

The research methodology of this thesis consists of combination of exploratory and a case study. To begin with, the exploratory research is carried out to find out what are happening, to seek new insights, to ask questions and assess phenomenon in a new light. It is helpful in deeper understanding of the problem. The energy management is a vast area. Initial focus is broad and narrowed down progressively as thesis progressed.

Accordingly, the first step is the developing of a theoretical framework of energy management based on detailed literature survey of the subject with the help of relevant books, journals and various websites related to the subject.

The second step is the analyzing of energy consumption of the company and find out ways to minimize the cost of energy consumption and to increase the efficiencies of the energy consumption of the highly energy utilized equipment, which in turn will help in development and competitive edge of the company.

Secondary data is used in this thesis. Secondary data is collected, to be analyzed, from various publications and official records available in the company. Both qualitative and quantitative analyses are carried out in this research.

CHAPTER 5: DESCRIPTION OF DATA ANALYSIS

5.1.Preliminary Energy Audit in EPPSC

The scanning energy audit model for large sites in the process industry like EPPSC is called the Preliminary Energy Audit. Although the main aim of the Preliminary Energy Audit is in line with the Walk Through Energy Audit, the size and type of the site requires a different approach.

In large industrial sites, only some areas and systems can be listed in advance as the probable sources for energy saving or cost of energy saving potential. Most of the work in the Preliminary Energy Audit is in building up a reliable informing of the present total energy consumption and defining the areas of the significant energy consumption and usually also of the probable energy saving or cost of energy measures.

Preliminary Energy Audit in EPPSC is performed through inspection of the following energy systems. These are:

- Building envelop,
- Boiler system,
- Steam pipeline distribution system,
- Heating, ventilation and air condition system (HVAC),
- Electric supply system,
- Lighting system,
- Motors system,
- Pumps system, and
- Common sense and interview with factory workers in order to identify energy conservation opportunities and indentify the major energy systems of the factory to perform the detail energy audit of the major systems.

From the above nine general energy systems, boiler and motors systems are selected to be discussed.

During the preliminary energy audit, the following tables for three years yearly energy utilization reports are obtained from EPPSC.

Table 5.1: Yearly Energy Utilization Report in EPPSC for 2014

Months	Product Achieved (ton)	Utilized Energy by Electric Steam Boilers (kWh)	Utilized Energy by Motors (kWh)	Total Utilized Energy (kWh)	Utilized Energy per ton of Product (kWh/ton)	Cost per ton of Product (Birr/ton)
January	481.31	1,245,083.12	321,028.74	1,566,111.86	3,253.85	1,329.52
February	398.82	1,269,600.05	280,978.76	1,550,578.81	3,887.92	1,588.60
March	649.65	1,987,033.50	386,666.38	2,373,699.88	3,653.81	1,492.95
April	472.75	1,222,939.57	316,430.41	1,539,369.98	3,256.20	1,330.48
May	705.91	1,917,654.53	437,306.34	2,354,960.87	3,336.06	1,363.11
June	970.17	2,509,697.06	577,626.01	3,087,323.07	3,182.25	1,300.27
July	757.70	2,051,628.18	464,806.36	2,516,434.54	3,321.15	1,357.02
August	624.20	1,689,264.93	321,426.85	2,010,691.78	3,221.23	1,316.20
September	765.20	2,071,029.65	468,788.79	2,539,818.44	3,319.16	1,356.21
October	644.44	1,819,200.00	346,942.84	2,166,142.84	3,361.28	1,373.42
November	628.15	1,544,900.00	308,957.90	1,853,857.90	2,951.30	1,205.90
December	620.59	1,533,599.70	350,326.51	1,883,926.21	3,035.70	1,240.39
2014 Year	7,718.89	20,861,630.29	4,581,285.89	25,442,916.18	3,296.19	1,346.82

Table 5.2: Yearly Energy Utilization Report in EPPSC for 2015

Months	Product Achieved (ton)	Utilized Energy by Electric Steam Boilers (kWh)	Utilized Energy by Motors (kWh)	Total Utilized Energy (kWh)	Utilized Energy per ton of Product (kWh/ton)	Cost per ton of Product (Birr/ton)
January	221.75	703,614.56	220,902.98	924,517.51	4,169.19	1,703.53
February	183.27	585,691.00	195,237.22	780,928.22	4,261.08	1,741.08
March	161.28	542,491.00	194,970.15	737,461.15	4,572.55	1,868.34
April	215.59	693,571.79	214,994.32	908,566.11	4,214.32	1,721.97
May	257.90	762,550.65	243,214.65	1,005,765.27	3,899.83	1,593.47
June	315.76	856,880.99	281,806.66	1,138,687.65	3,606.18	1,473.49
July	703.56	1,920,013.46	435,850.53	2,355,863.99	3,348.49	1,368.19
August	540.35	1,497,811.52	376,228.62	1,874,040.14	3,468.20	1,417.11
September	676.96	1,851,202.90	418,433.63	2,269,636.53	3,352.69	1,369.91
October	507.91	1,413,893.68	357,916.06	1,771,809.74	3,488.43	1,425.37
November	560.11	1,548,927.94	387,383.25	1,936,311.19	3,457.02	1,412.54
December	563.85	1,558,555.58	389,494.36	1,948,049.94	3,454.91	1,411.68
2015 Year	4,908.29	13,935,205.07	3,716,432.53	17,651,637.60	3,596.29	1,469.44

Table 5.3: Yearly Energy Utilization Report in EPPSC for 2016

Months	Product Achieved (ton)	Utilized Energy by Electric Steam Boilers (kWh)	Utilized Energy by Motors (kWh)	Total Utilized Energy (kWh)	Utilized Energy per ton of Product (kWh/ton)	Cost per ton of Product (Birr/ton)
January	501.16	1,743,085.58	256,678.61	1,999,764.19	3,990.27	1,630.42
February	518.90	1,690,805.80	246,871.87	1,937,677.67	3,734.20	1,525.79
March	404.23	1,673,792.80	295,789.99	1,969,582.79	4,872.43	1,990.88
April	453.37	1,845,599.20	312,475.97	2,158,075.17	4,760.08	1,944.97
May	540.64	2,068,800.00	311,229.71	2,380,029.71	4,402.25	1,798.76
June	741.95	2,109,600.00	365,954.11	2,475,554.11	3,336.55	1,363.31
July	288.64	1,096,800.00	340,133.43	1,436,933.43	4,978.29	2,034.13
August	402.69	1,536,000.00	475,612.84	2,011,612.84	4,995.44	2,041.14
September	511.96	1,601,999.30	467,119.63	2,069,118.93	4,041.57	1,651.39
October	Data for these months cannot be obtained, because the thesis ends on the middle of October.					
November						
December						
2016 Year (for 9 Months)	4,363.54	15,366,482.68	3,071,866.16	18,438,348.84	4,225.55	1,726.56
2016 Year (for 12 Months) (Estimation)	5,818.05	20,488,643.57	4,095,821.55	24,584,465.12	4,225.55	1,726.56

Table 5.4: Average Values of Product Achieved and Energy Utilized for the Three Years Yearly Energy Utilization Report in EPPSC

Year	Total Product Achieved (ton)	Utilized Energy by Electric Steam Boilers (kWh)	Utilized Energy by Motors (kWh)	Total Utilized Energy (kWh)	Utilized Energy per ton of Product (kWh/ton)
2014	7,718.89	20,861,630.29	4,581,285.89	25,442,916.18	3,296.19
2015	4,908.29	13,935,205.07	3,716,432.53	17,651,637.60	3,596.29
2016	5,818.05	20,488,643.57	4,095,821.55	24,584,465.12	4,225.55
Average	6,148.41	18,428,492.98	4,131,179.99	22,559,672.97	3,706.01

Table 5.5: Maximum and Minimum Values of Utilized Energy per ton of Product for the Three Years Yearly Energy Utilization Report in EPPSC

Year	Maximum Value of Utilized Energy per ton of Product (kWh/ton)	Minimum Value of Utilized Energy per ton of Product (kWh/ton)
2014	3,887.92	2,951.30
2015	4,572.55	3,348.49
2016	4,995.44	3,336.55

Table 5.6: Evaluation of Maximum and Minimum Values of Utilized Energy per ton of Product in EPPSC Based on Benchmarked Values

	Minimum Values	Maximum Values
Utilized Energy per ton of Product (kWh/ton) in EPPSC	2,951.30	4,995.44
Benchmark Values of Utilized Energy per ton of Product (kWh/ton)	1,450.00	1,650.00

Source for Benchmark: UNIDO (2010): Global Industrial Energy Efficiency Benchmarking. November 2010.

From the above tables, it can be easily known that the EPPSC consumes very high amount of energy compared with the international standard for energy consumption to produce paper. Considering the above facts, we now suggest the following solutions to solve the afore-mentioned energy consumption problems and their consequences like minimizing the cost of energy consumption:

5.1.1. Inspection of Boiler System

During the preliminary energy audit of boiler system, it is known that the boiler used for paper and paperboard production nowadays in the company is the electric steam boiler which is not economically acceptable because of the high cost of electricity everywhere in the world. Therefore, cost of energy saving opportunities must be found especially for the boiler system.

The following cost of energy saving opportunity is discovered. This is:

Electric boilers have no flue loss through a chimney. The efficiency for electric boilers is between 95 % and 100 %. However, despite their high efficiency, the higher cost of electricity in most parts of the world makes all-electric boilers an uneconomic choice. Source: "Furnaces and Boilers." Energy.gov. N.p., n.d. Web. 26, Apr. 2014.

Therefore, it is a must to find any other option to substitute the electric steam boiler to make the company more profitable by saving the unnecessary wasting of the production costs. In other words, it is a must to find economic choice for the electric steam boiler. On my point of view, wood biomass boiler can perfectly be the economic choice for the electric steam boiler, because wood biomass has a very high amount of Lower Heating Value (LHV) when compared with other biomasses and it is also environmentally friendly.

A casual analysis suggests that renewable energy markets are projected to grow strongly in the coming decade and beyond, led by policies such as European Commission 2020 Directives to Member States, which are expected to accelerate the development of renewable heating. Source: Renewable Energy.World.com (Biomass Outlook 2014: Is biomass about to go bang?) What about the future of biomass consumption in Ethiopia? Don't forget that the Ethiopian Electric Power Corporation has proposed to increase the tariff of electric energy consumption by 50 % in the very near future. This definitely shows that the electric steam boiler can never be the economic choice for industries in Ethiopia. It may be used as stand-by choice.

5.1.2. Inspection of Motors System

During the preliminary energy audit of motors system, the following tabular data is obtained for the most basic units in paper production processes from the EPPSC by careful measurements:

Table 5.7: Nameplate and Input Powers for Highly Energy Consuming Motors in EPPSC

№	Highly Energy Consuming Motors	Nameplate Full Rated Power in kW	Input Power at Full-Rated Load in kW
1	Hydra-Pulper Mill Drive Motor	149.20	279.00
2	Hydra-Refiner Motor	298.40	516.54
3	Dryer's Line-Shaft Motor	373.00	273.02
4	Stock Preparation Motor	174.50	226.00
5	Dewatering Motor	337.30	530.44
6	Water Supply Motor	100.00	120.00
	Total	1,432.40	1,945.00

The first three of the motors listed in the above table are selected for detailed energy auditing because they are suitable to take measurements and the nameplate data can be easily obtained in the company. In addition, they were bought before 50 years i.e. they are very old motors. It is well-known that the lifespan of industrial motors is only 20 years. Thus, it had not been economical to use the afore-mentioned motors for the previous more than 30 years. Hereafter, they should be changed with new industrial motors to minimize the cost of electric energy consumption.

5.2.Detailed Energy Audit

5.2.1. Replacement of Electric Steam Boiler by Wood Biomass Boiler

5.2.1.1. Collected Data for Boiler

5.2.1.1.1. Nameplate Data of Electric Steam Boilers

The boiler that is now used in the EPPSC to generate steam for process heating is the electric steam boiler. The company has two boilers used simultaneously or interchangeably based on the need of the electric energy. The following two tables represent the nameplate data for the two boilers existing in EPPSC:

Table 5.8: Nameplate Data for the Smaller Electric Steam Boiler

Manufacturer	Grarini Aval
Serial №	280.11
Year	2011
Capacity	3,000 kW
Steam Production	4,302 kg/h
Safety Valve Set Pressure	20 bar
Fluid Group	2
Capacity	IV
Temperature TS	Min. 0 ^{0}C & Max. 215 ^{0}C
Maximum Working Pressure PS	20 bar
Volume	13,355 Lt
Pressure Test Date	22/11/2011
Pressure Test	36.3 bar
Voltage	660 V
Frequency	50 Hz
Empty Weight	9,920 kg
Filling Mass	10,000 kg

Table 5.9: Nameplate Data for the Larger Electric Steam Boiler

Manufacturer	Grarini Aval
Type	GEV 6000
Serial №	257.13
Design Code	VSG ED.95
Year	2013
Capacity	6,000 kW
Steam Production	8,600 kg/h
Safety Valve Set Pressure	20 bar
Fluid Group	2
Capacity	IV
Temperature TS	Min. 0 ^{0}C & Max. 215 ^{0}C
Maximum Allowable Pressure PS	20 bar
Maximum Operating Pressure	20 bar
Volume	14,070 Lt
Pressure Test Date	29/11/2013
Pressure Test	34.4 bar
Voltage	660 V
Frequency	50 Hz
Empty Weight	9,000 kg
Filling Mass	10,630 kg

5.2.1.1.2. Measured Data for Electric Steam Boilers

The following three measurements are taken, in a day, for voltage and current from the boiler

5.2.1.1.2.1. Measured Values of Voltage & Current for Larger Steam Boiler

Voltage (Volts)	Average Voltage (Volts)	Current (kAmps)	Average Current (kAmps)
$V_1 = 670$	$V = 670$	$I_1 = 4.50$	$I = 4.50$
$V_2 = 670$		$I_2 = 4.50$	
$V_3 = 670$		$I_3 = 4.50$	

5.2.1.1.2.2. Measured Values of Voltage & Current for Smaller Steam Boiler

Voltage (Volts)	Average Voltage (Volts)	Current (kAmps)	Average Current (kAmps)
$V_1 = 660$	$V = 665$	$I_1 = 2.80$	$I = 3.00$
$V_2 = 665$		$I_2 = 3.00$	
$V_3 = 670$		$I_3 = 3.20$	

5.2.1.1.2.3. Measured Values of Power Factors

Devices	Corrected Values of Power Factors
Electric Steam Boilers	1.00
Electric Motors	0.87

Notation: The electric steam boilers have a purely resistive circuit. For the purely resistive circuit, the power factor is 1 (perfect), because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length.

For the electric motors, the power factors are corrected by the Power Factor Corrector in order to have one standard power factor in the company based on the requirement of the EEPCo.

5.2.1.1.2.4. Measured Values of Mass Flow Rates

Items	Measured Values (kg/h) Average Values
1. Steam Produced	11,097.15
2. Condensate Return	8,119.75
3. Feed Water	11,967.91
4. Makeup Water	3,829.03

5.2.1.1.2.5. Measured Values of Temperatures

Items	Measured Values (^{0}C) Average Values
1. Steam Produced	190
2. Condensate Return	90
3. Feed Water	85
4. Makeup Water	20

5.2.1.1.2.6. Measured Values of Pressure

Item	Measured Values (bar) Average Values	Pressure Set Value (bar)
Steam Produced	9.00	11.00

5.2.1.2. Calculation of Average Electric Input Power to Electric Steam Boilers

From table 5.4, it can be known that the average value of the annual total utilized energy by electric motors is 4,131,179.99 kWh. From table 5.7, the total input power for the highly energy consuming motors at full-rated load is obtained to be 1,945.00 kW.

Now, it is possible to calculate the average annual working hours in the company as follows:

$$\textit{Average}\text{ Annual Working Hours} = \frac{\textit{Annual}\text{ Total Utilized Energy by Electric Motors}}{\textit{Total}\text{ Input Power by Electric Motors}} \quad \text{(5.1)}$$

$$\textit{Average}\text{ Annual Working Hours} = \frac{4{,}131{,}179.99\text{ kWh}}{1{,}945.00\text{ kW}}$$

$$\textit{Average}\text{ Annual Working Hours} = 2{,}124\text{ hr.}$$

In addition to the above,

From table 5.4, it can be known that the average value of total utilized energy by electric steam boilers is 18,428,492.98 kWh.

Now,

$$\textit{Average}\text{ Input Power to Boilers} = \frac{\textit{Total}\text{ Annual Utilized Energy by Boilers}}{\textit{Number}\text{ of Working Hours in a Year}} \quad \text{(5.2)}$$

$$\textit{Average}\text{ Input Power to Boiler} = \frac{18{,}428{,}492.98\text{ kWh}}{2{,}124\text{ hr}}$$

$$\textit{Average}\text{ Input Power to Boiler} = 8{,}676.32\text{ kW.}$$

5.2.1.3. Calculation of Mass Flow Rates of Feed-Water and Steam Production

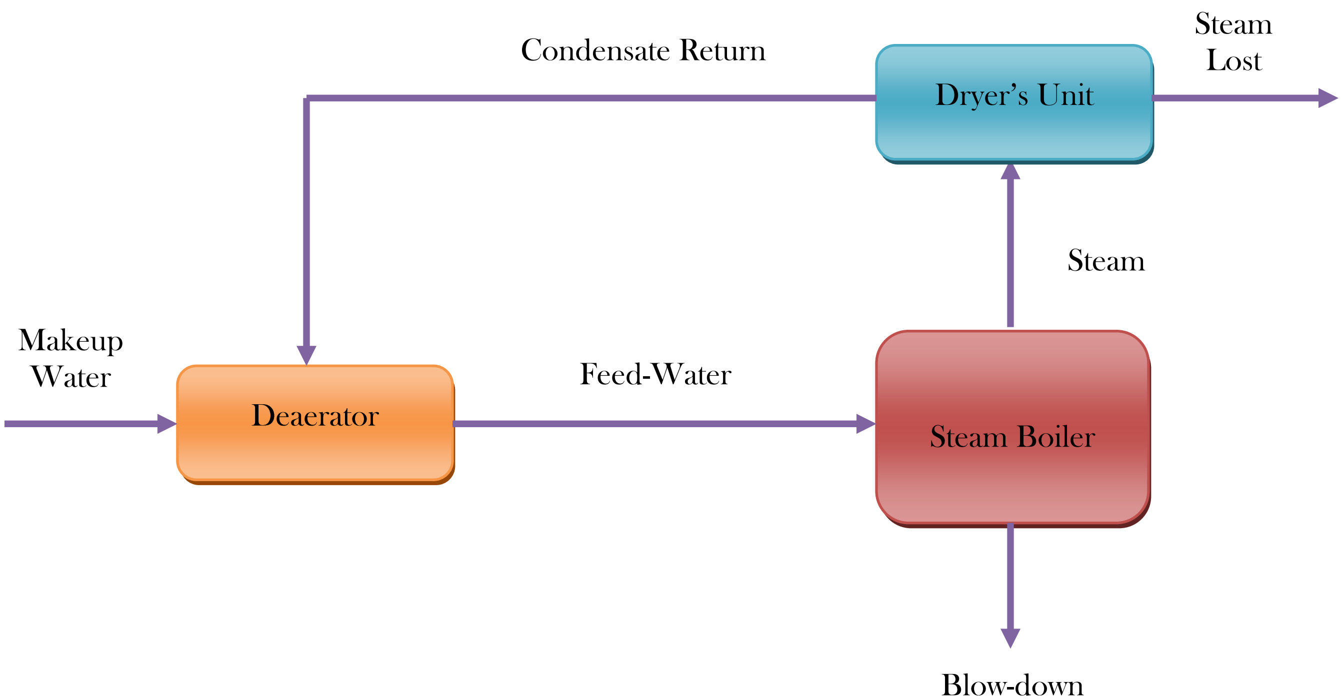


Figure 5.1: Boiler Feed-Water, Steam Generation and Blow-down Relationships

Benefits of Deaerator:

Deaerator provides many benefits to a steam-plant system, including:

- Serving as a surge collection tank for process condensate return.
- Blending hot return condensate and cold makeup water.
- Preheating feed-water uniformly to improve boiler efficiency.
- Removing oxygen (O_2) and carbon dioxide (CO_2) from feed-water to mitigate corrosion.
- Providing a location for feeding and blending chemicals and testing protocol.
- Providing a constant, pressurized supply of water to boiler feed pumps.
- Providing a convenient location for instrument controls and feed-water test data.
- Helping to ensure precise drum water level and pressure inside of a boiler.

Benefits of Blow-down:

Rate of blow-down is a rate normally expressed as a percentage of the water feed. In the case of boilers, rate of blow-down is the removal rate of water from a boiler. Its purpose is to control boiler water parameters within prescribed limits to minimize:

- Scale
- Corrosion
- Carryover
- Other problems

Blow-down is also used to remove suspended solids from the system. Insufficient blow-down may lead to carryover of boiler water into the steam, or the formation of deposits.

The recommended rate of blow-down is from 4% to 8% of the rate of feed-water.

In general the benefits of blow-down are expressed as follows:

- Minimizes wasting of energy.
- Less maintenance and repair cost (minimized carryover and deposits).
- Saves manual supervision for other tasks (with automatic control).
- Cleaner and more efficient steam.
- Reduced operating cost (reduction in consumption, disposal, treatment & heating of water).

To calculate mass flow rates of feed-water and steam production:

Assumptions:

- Deaerator provides feed-water near the boiling temperature for the deaerator's set operating pressure. (Saturated Liquid)
- Steam, boiler, and blow-down pressures are the same.
- Combustion efficiency is the % of fuel energy that is directly added to the feed-water and not otherwise lost or used.
- Blow-down rate is the % of incoming feed-water mass flow rate that leaves the boiler as a saturated liquid at boiler pressure.
- Do not include any evaluation of any complex boiler configurations or fluctuations in operation.
- Energy from motors (pumps, fans, etc.) is not considered.
- Boiler and fuel types are not considered.

Based on the above-mentioned assumptions,

Feed-Water Flow Rate = Condensate Return Flow Rate + Makeup Water Flow Rate

Feed-Water Flow Rate = Steam Production Flow Rate + Blow-down Flow Rate

Steam Production Flow Rate = Feed-Water Flow Rate – Blow-down Flow Rate

Blow-down Flow Rate = 6 % of Feed-Water Flow Rate

Steam Production Flow Rate = Feed-Water Flow Rate – 6 % Feed Water Flow Rate

Steam Production Flow Rate = 94 % Feed-Water Flow Rate

In addition,

Average Electric Steam Boiler Input Power = 9,329.68 kW

Efficiency of the Electric Steam Boiler = 0.96

Please, be aware of the fact that the age and type of boiler you have affects how efficient it is. Remind that the smaller electric steam boiler was bought in 2011 and the larger one in 2013.

Now,

$$\text{Output Power} = \text{Input Power} \times \eta \qquad (5.3)$$

$$Output\ Power = 8,676.32\ \text{kW} \times 0.96$$

$$Output\ Power = 8,329.27\ \text{kW}.$$

Moreover,

$$Output\ \text{Power} = \text{Net Thermal Output}$$

$$\text{Output Power} = \dot{m}_{Steam} \times h_{Steam} - \dot{m}_{Feed-\text{Water}} \times h_{Feed-\text{Water}} \qquad (5.4)$$

Where:

$\dot{m}_{Steam}$ = Mass Flow Rate of Steam Produced,

h_{Steam} = Specific Enthalpy of Steam Produced,

$\dot{m}_{Feed-\text{Water}}$ = Mass Flow Rate of Feed-Water, &

$h_{Feed-\text{Water}}$ = Specific Enthalpy of Feed-Water.

We already obtained that

$$\dot{m}_{Steam} = 0.94 \times \dot{m}_{Feed-\text{Water}}$$

Thus,

$$Output\ \text{Power} = 0.94 \times \dot{m}_{Feed-\text{Water}} \times h_{Steam} - \dot{m}_{Feed-\text{Water}} \times h_{Feed-\text{Water}}$$

$$Output\ \text{Power} = \dot{m}_{Feed-\text{Water}} \times (0.94 \times h_{Steam} - h_{Feed-\text{Water}})$$

As a result,

$$\dot{m}_{Feed-\text{Water}} = \frac{Output\ \text{Power}}{0.94 \times h_{Steam} - h_{Feed-\text{Water}}}$$

We have the following measurements:

Average Temperature of the Steam Produced = 190 ^{0}C

Average Pressure of the Steam Produced = 9 bar = 0.9 MPa

Temperature of the Feed-Water = 85 ^{0}C

To find the Specific Enthalpy of Steam Produced:

By reading from the Steam Table, $h_{Steam\ @\ \text{P = 0.9 MPa \& T = 190}\ ^0\text{C}} =$ 2808.57 kJ/kg

To find the Specific Enthalpy of Feed Water:

By reading from the Saturated Temperature Table for Steam,

$$h_{Feed\ \text{Water @ T = 85}^0\text{C}} = h_{f\ \text{@ T = 85}^0\text{C}} = 355.697 \text{ kJ/kg}$$

Now,

$$\dot{m}_{Feed-\text{Water}} = \frac{8,329.27 \text{ kW}}{0.94 \times 2808.57 \text{ kJ/kg} - 355.697 \text{ kJ/kg}}$$

$$\dot{m}_{Feed-\text{Water}} = 3.65\ kg/\text{s} = 13,140.00 \text{ kg/h} = 13.14 \text{ tons/h.}$$

Remark: From repeated experimental measurements taken in EPPSC,

$$\dot{m}_{Condensate\ \text{Return}} \approx 68.75\ \% \dot{m}_{Steam}$$

Finally,

$$\dot{m}_{Steam} = 0.94 \times \dot{m}_{Feed-Water} = 0.94 \times 3.65 \text{ kg/s} = 3.43 \text{ kg/s} = 12,348.00 \text{ kg/h} = 12.35 \text{ tons/h.}$$

Consequently,

$$\dot{m}_{Condensate\ \text{Return}} \approx 68.75\ \% \dot{m}_{Steam} = 0.6875 \times 3.65 \text{ kg/s} = 2.51 \text{ kg/s} = 9,036.00 \text{ kg/h} = 9.04 \text{ tons/h.}$$

To find the Mass Flow Rate of the Makeup Water:

$$\dot{m}_{Feed-\text{Water}} = \dot{m}_{Condensate\ \text{Return}} + \dot{m}_{Makeup\ \text{Water}}$$

Thus,

$$\dot{m}_{Makeup\ \text{Water}} = \dot{m}_{Feed-\text{Water}} - \dot{m}_{Condensate\ \text{Return}} \qquad (5.5)$$

$$\dot{m}_{Makeup\ \text{Water}} = 3.65\ \text{kg/s} - 2.51\ \text{kg/s} = 1.14\ \text{kg/s} = 4{,}104.00\ \text{kg/h} = 4.10\ \text{tons/h}.$$

Summary:

Table 5.10: Calculated Values of Mass Flow Rates

Mass Flow Rates	Values (kg/s)	Values (kg/h)	Values (tons/h)
Steam Produced	3.43	12,348.00	12.35
Condensate Return	2.51	9,036.00	9.04
Feed-Water	3.65	13,140.00	13.14
Blow-down	0.22	792.00	0.79
Makeup Water	1.14	4,104.00	4.10

Table 5.11: Measured Values of Mass Flow Rates

Mass Flow Rates	Average Values (kg/h)
Steam Produced	11,097.15
Condensate Return	8,119.75
Feed-Water	11,967.91
Makeup Water	3,829.03

5.2.1.4. Basic Parameters to Change Electric Steam Boiler by Wood Biomass Boiler

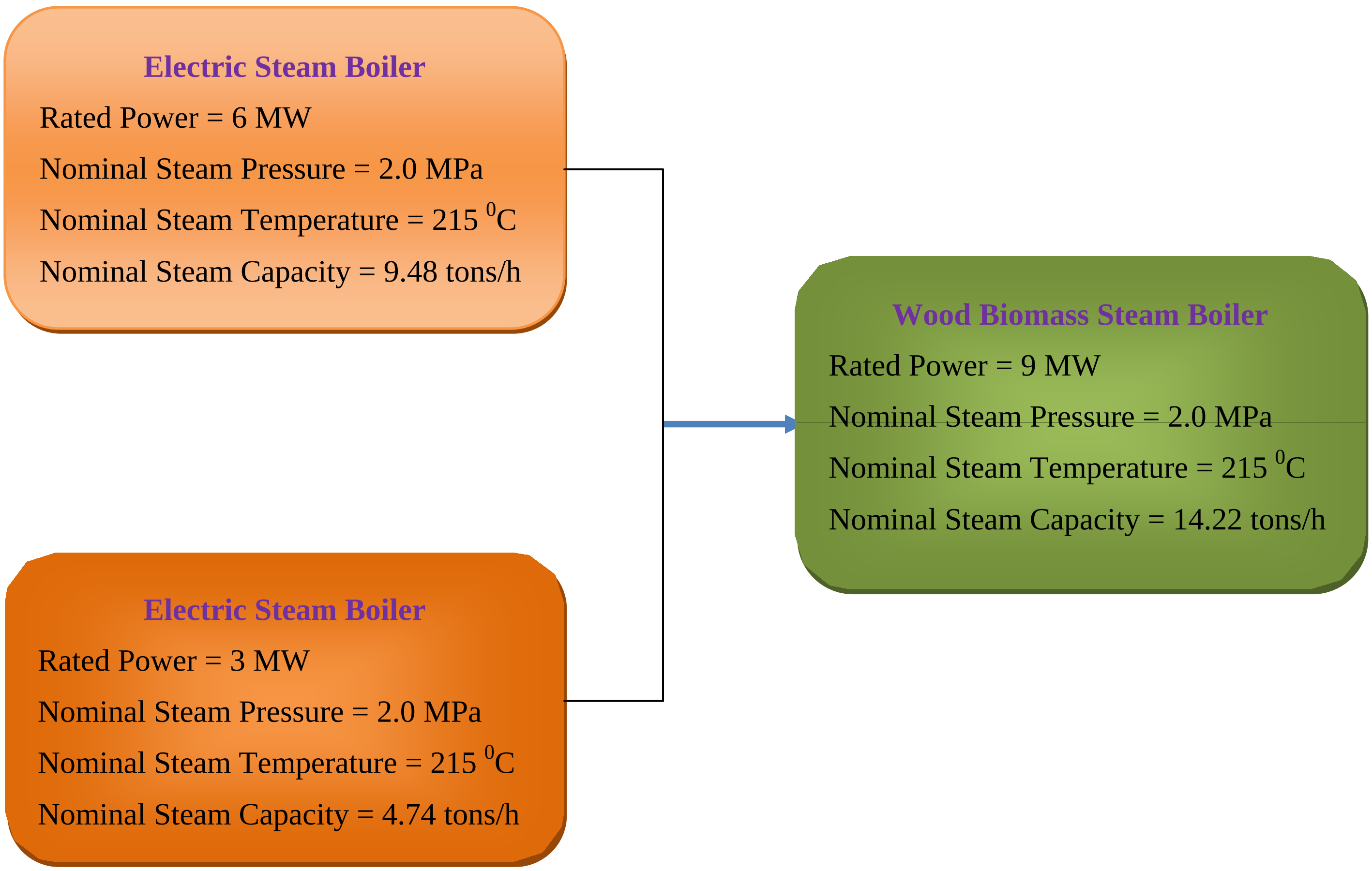


Figure 5.2: Basic Parameters to Change Electric Steam Boiler by Wood Biomass Boiler

5.2.1.5. Why Wood Biomass Boiler is Recommended?

5.2.1.5.1. Wood Biomass Boiler: Environmentally Friendly & Economic Choice

Biomass boilers, in general, are an excellent investment both in environment and economic terms.

Environment Term: As well as producing less CO_2, biomass produces less (almost negligible) other harmful chemicals than fossil fuels too. Sulfur dioxide is a typical by-product of fossil fuel burning, and is a major contributor to acid rain.

Economic Term: With the finite nature of fossil fuels, predictions indicate that the price of oil, gas, coal and electricity will only go one way. By making the change to a more sustainable form of heating now, we are not only going to be able to take advantage of the economic returns through lower cost, but also protecting ourselves from the future price rises in oil, gas, coal and electricity.

5.2.1.5.2. Biomass Combustion Systems

a) Biomass

Biomass is a renewable energy technology and is classified as carbon neutral. As trees grow, they absorb carbon from the atmosphere (and produce oxygen). This carbon is stored in the tree. If this tree was to be left to decompose, this captured carbon would be released back to the atmosphere over a few years, burning that material will also release the carbon but will make use of the energy in the process.

b) Combustion

Combustion has three requirements – fuel, air and heat. If any of these three are removed, burning stops. When all three of them are available in the correct proportion, combustion is self-sustaining, because the fuel releases excess heat to initiate further burning.

An efficient combustion requires sufficient:

- High temperature,
- Excess air (oxygen),
- Combustion time, and
- Mixture.

c) Biomass Combustion

Biomass combustion is the main technology route for bio-energy and is responsible for over 90 % of the global contribution to bio-energy. The selection and design of a biomass combustion system is determined by a number of factors including:

- The characteristics of the fuel to be used,
- The energy capacity and pattern of demand to be met,
- The costs and performance of the equipment, and
- Local legislation relating to buildings and the environment.

A biomass system usually consists of the following components:

- Biomass boiler,
- Fuel storage,
- Chimney,
- Hydronic distribution system for the hot water produced by the boiler,
- Hydronic discharge systems (floor heating or radiators), and
- A central control device with an outdoor temperature sensor.

In biomass heating systems, the fuel is transported from the storage facility to the combustion chamber, where it is combusted. A fan is installed to improve the heat transfer and supply sufficient air for an optimal combustion. A circulation pump transports feed-water (the heated water) through the distribution system. To reduce heat losses to the boiler room, the boiler and all pipes should be highly insulated.

Some of the features of a modern biomass heating include:

- High fuel efficiency (80 % - 90 %),
- Ultra low emissions,
- Fully automatic operation, and
- Low fuel costs.

5.2.1.5.3. Advantages and Disadvantages of Wood Biomass

a. Advantages of Wood Biomass

- It is a non-food, organic material that as a feedstock will not compete with agricultural interests for growing food crops.
- It is a renewable resource.
- It has positive benefits to the environment because of the lower energy requirements to manufacture products than comparable non-wood materials (e.g. wood vs. steel).
- It can reduce wildfire hazard when it is removed from the forest or wild-land urban interface.
- When burned to produce energy, it emits an amount of carbon dioxide that is comparable to the amount of CO_2 released by wood during natural degradation. Since trees take in CO_2 during photosynthesis, using wood to produce energy is considered "carbon neutral".

b. Disadvantages of Wood Biomass

- **Limited Availability**: It is difficult to obtain enough feedstock near large processing plants.
- **High Cost**: It is associated with the harvest, transportation and storage of wood biomass.
- **Low-Energy Density**: It has a much lower energy density (unit of energy per unit of volume) than fossil fuels.
- **Technological Difficulties**: The unwilling nature of wood and its complex chemistry make it a technologically difficult feedstock to use in chemical and energy processing.
- **Competition**: The growth of wood biomass markets may divert higher-quality wood away from traditional wood product markets.

5.2.1.6. Full Product Specification of Proposed Wood Biomass Boiler

Let's choose the wood biomass boiler manufactured by Lan Chappell Biomass Boiler Services, based in the North East, covering the UK and Ireland. The following is full product specification of the selected boiler.

Table 5.12: 9.0 MW & 2.0 MPa Wood Logs Biomass Boiler Technical Parameters

Parameters	Values
Rated Power	9.0 MW
Rated Steam Capacity	14.22 tons/h
Rated Outlet Pressure	2.0 MPa
Rated Outlet Temperature	215 ^{0}C
Inlet Water Temperature	90 ^{o}C
Cold Air Temperature	20 ^{0}C
Testing Pressure	2.0 MPa
Exhaust Gas (Stack) Temperature	160 ^{0}C
Design Air-Fuel Ratio	1.65
Design Thermal Efficiency	84.0 %
Boiler Water Voulme	7.5 m^3
Total Electricity Consumption	53.35 kW

Table 5.13: Full Set Wood Logs Biomass Boiler System Equipment List

Product Nmae	Quantity (Set)	Product Name	Quantity (Set)
Boiler Main Part	1	Smoke Chimney	1
Draft Fan	1	Smoke Ducting	1
Forced Fan	1	Fuel Feeder	1
Electric Controller	1	Slag Remover	1
Valve	1	Ceramic-Cyclone	1
Pressure Gauge	1	Water Treatment Equipment	1
Grate Speed Reducer	1	Water Pump	2

5.2.1.7. Properties Analyses for the Selected Wood Biomass

5.2.1.7.1. Ultimate and Proximate Analyses of Wood Biomass

Figure 5.3: Wood Logs

5.2.1.7.1.1. Ultimate Analysis of the Selected Wood Biomass in Ethiopia

Table 5.14: Ultimate Analysis of the Selected Wood Biomass in Ethiopia

Wood Log (Stacked-Air Dry: 15 % MC)

Elements	Measured Values
Carbon	48.00 %
Hydrogen	5.70 %
Oxygen	30.00 %
Nitrogen	0.50 %
Sulfur	0.05 %
Ash	0.75 %
Moisture	15.00 %
Total	100.0 %

Source: Laboratory Report of EREDPC (Ethiopian Rural Energy Development and Promotion Center)

5.2.1.7.1.2. Proximate Analysis of the Selected Wood Biomass in Ethiopia

Table 5.15: Proximate Analysis of the Selected Wood Biomass in Ethiopia

Items	Values
Volatile Matters	68.05 %
Fixed Carbon	16.20 %
Ash	0.75 %
Moisture	15.00 %
Total	100.00 %

Density = 425 kg/m^3

Source: Laboratory Report of EREDPC (Ethiopian Rural Energy Development and Promotion Center)

5.2.1.7.2. Heating Values of the Selected Wood Biomass in Ethiopia

Lower Heating Value (LHV) vs Higher Heating Value (HHV)

Lower Heating Value (LHV): The amount of heat liberated by the complete combustion, under specific conditions, by a unit volume of a gas or of a unit mass of a solid or liquid fuel, in the determination of which the water produced by combustion of the fuel is assumed to be completely condensed and its latent and sensible heat made available.

Higher Heating Value (HHV): The amount of heat generated by the complete combustion, under specified conditions, by a unit volume of a gas or a unit mass of a solid or liquid fuel, in the determination of which the water produced by the combustion of the fuel is assumed to remain as vapor.

Measured Lower and Higher Heating Values:

Table 5.16: Measured Heating Values of the Selected Wood Biomass in Ethiopia

Heating Values	Measured Values (MJ/kg)
LHV	14.65
HHV	18.30

Source: Laboratory Report of EREDPC (Ethiopian Rural Energy Development and Promotion Center)

5.2.1.7.3. Calculation of HHV and LHV

5.2.1.7.3.1. Calculation of HHV

Higher heating value can be estimated from the composition of the fuel (Gaur and Reed 1995),

$$HHV_d = 0.35X_C + 1.18X_H + 0.10X_S - 0.02X_N - 0.01X_O - 0.02X_{Ash} \qquad (5.6)$$

Where:

X is the mass fractions (percent mass dry basis) for Carbon (C),

Hydrogen (H),

Sulfur (S),

Nitrogen (N),

Oxygen (O), and

ash content (Ash).

The unit of HHV in the above equation is in MJ/kg dry mass. This equation shows that the elements Carbon, Hydrogen, and Sulfur increase the heating value whereas the elements Nitrogen, Oxygen, and Ash suppress the heating value.

Therefore,

$$HHV_d = 0.35 \times 48.00 + 1.18 \times 5.70 + 0.10 \times 0.05 - 0.02 \times 0.50 - 0.10 \times 30 - 0.02 \times 0.75$$

$$HHV_d = 20.51 \text{ MJ/kg.}$$

There is also

$$HHV_d = \frac{HHV}{1 - MC} \leftrightarrow HHV = HHV_d \times (1 - MC) \qquad (5.7)$$

Where:

HHV_d = Higher heating value of the biomass in bone dry biomass,

HHV = Higher heating value determined by the calorimeter, and

MC = Moisture content of the biomass in decimal wet mass fraction.

Therefore,

$$HHV = HHV_d \times (1 - MC) = 20.51 \times (1 - 0.15) = 17.43 \text{ MJ/kg.}$$

5.2.1.7.3.2. Calculation of LHV

An estimate of the LHV or the net heating value (NHV) is obtained from the measured HHV by substracting the heat of vaporization of water in the products.

$$LHV = HHV(1-MC) - 2.447MC \qquad (5.8)$$

Where LHV is the net (or lower) heating value in MJ/kg and M is the wet basis moisture content (mass fraction decimal). The constant 2.447 is the latent heat of vaporization of water in MJ/kg at 25 ^{0}C.

Therefore, $LHV = 18.30 \times (1-0.15) - 2.447 \times 0.15 = 15.19$ MJ/kg.

Summary:

Table 5.17: Calculated Heating Values of the Selected Wood Biomass in Ethiopia

Heating Values	Calculated Values (MJ/kg)
LHV	15.19
HHV	17.43

5.2.1.7.3.3. Plotting of Lower Heating Value over Moisture Content Graph

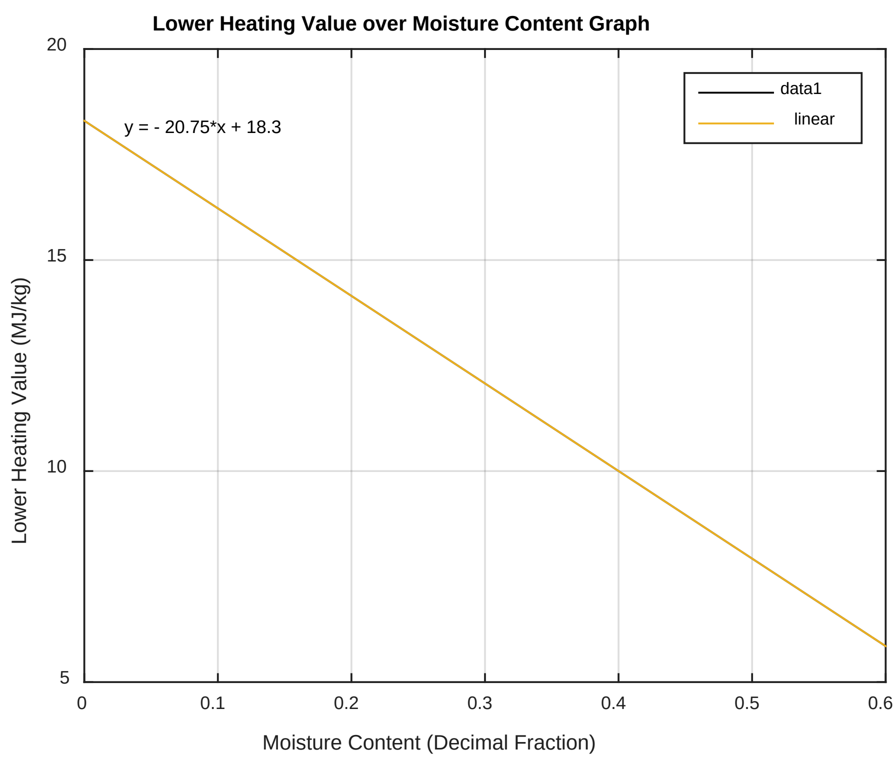


Figure 5.4: Graph of Lower Heating Value over Moisture Content

5.2.1.8. Calculation of Mass Flow Rate of Wood Biomass Consumption

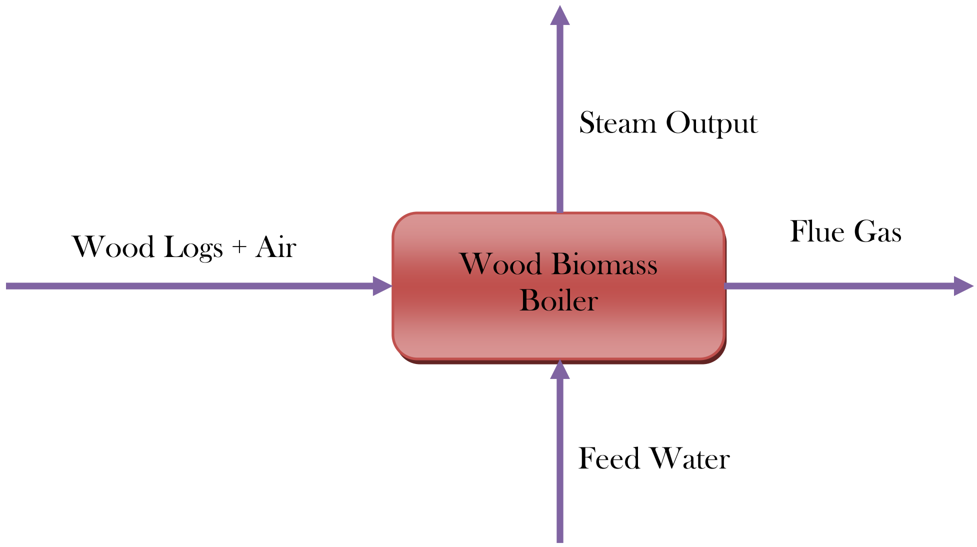


Figure 5.5: Materials Balance on Wood Biomass Boiler

$$\textit{Boiler}\ \text{Efficiency} = \frac{\textit{Heat Addition}\ \text{to Steam}}{\textit{Lower Heat in Fuel}} \times 100$$

$$\text{Boiler Efficiency} = \frac{\dot{m}_{Steam} \times h_{Steam} - \dot{m}_{Feed-\text{Water}} \times h_{Feed-\text{Water}}}{\dot{m}_{Fuel} \times \textit{Lower Heating}\ \text{Value}}$$

$$\dot{m}_{Fuel} = \frac{\dot{m}_{Steam} \times h_{Steam} - \dot{m}_{Feed-\text{Water}} \times h_{Feed-\text{Water}}}{\text{Boiler Efficiency} \times \textit{Lower}\ \text{Heating Value}} \quad (5.9)$$

Remark : Boiler efficiency must be in decimal form.

From the Electric Steam Boiler, we need the following to be fulfilled for the proposed Wood Biomass Boiler:

Temperature of Steam Produced = 190 ^{0}C.

Pressure of Steam Produced = 9 bar.

Temperature of the Feed-Water = 85 ^{0}C.

Mass Flow Rate of Steam Produced = 3.43 kg/s.

Mass Flow Rate of Feed-Water = 3.65 kg/s.

Consequently,

By reading from the Steam Table, $h_{Steam\ @\ P = 0.90MPa\ \&\ T = 190^0C} = 2808.57\ kJ/kg$

By reading from the Saturated Temperature Table for Steam,

$h_{Feed\ Water\ @\ T = 85^0C} = h_{f\ @\ T = 85^0C} = 355.697\ kJ/kg$

Now,

$$\dot{m}_{Fuel} = \frac{\dot{m}_{Steam} \times h_{Steam} - \dot{m}_{Feed-Water} \times h_{Feed-Water}}{\text{Boiler Efficiency} \times \textit{Lower}\ \text{Heating Value}}$$

$$\dot{m}_{Fuel} = \frac{3.43\ kg/s \times 2808.57\ kJ/kg - 3.65\ kg/s \times 355.697\ kJ/kg}{0.84 \times 14650\ kJ/kg}$$

$$\dot{m}_{Fuel} = 0.677\ kg/s = 40.62\ kg/min = 2{,}437.20\ kg/h = 2.44\ tons/h.$$

This value of the mass flow rate of the wood biomass fuel is theoretical (acceptable) value. The accepted tolerance for the relative error of experimental (measured) value is within ±10%. Thus, the measured value will have to lie between 2,193.48 kg/h and 2,680.92 kg/h.

5.2.1.9. Determination of Combustion Properties of Wood Biomass

5.2.1.9.1. Calculation of Chemical (Molecular) Formula of Wood Biomass

First, let's remind the Ultimate Analysis of the Wet Wood Biomass

Ultimate Analysis of Wood Biomass	
Elements	Measured Values
Carbon	48.00 %
Hydrogen	5.70 %
Oxygen	30.00 %
Nitrogen	0.50 %
Sulphur	0.05 %
Ash	0.75 %
Moisture	15.00 %
Total	100.00 %

The ultimate analysis is generally reported on an "as received' basis, including the moisture in the chemical analysis. The molar composition may be determined by dividing each of the mass percentages by the atomic weight of the constituent. For convenience in stoichiometric calculations, the composition is then normalized with respect to carbon:

Element	Weight %	Atomic Weight (gm/mol)	Mol/100 g of Fuel	Mol/mol C
C	48.00	12	48.00÷12 = 4.000	4.000÷4.000 = 1.00
H	5.70	1	5.70÷1 = 5.700	5.700÷4.000 = 1.425
O	30.00	16	30.00÷16 = 1.875	1.875÷4.000 = 0.469
N	0.50	14	0.50÷14 = 0.03571	0.03571÷4.000 = 0.008928
S	0.05	32	0.05÷32 = 0.001563	0.001563÷4.000 = 0.0003908
Ash	0.75			0.75÷4.000 = 0.1875 gm/mol C
Moisture	15.00			15÷4.000 = 3.75 gm/mol C

The chemical formula that can be used to describe this particular wood biomass is , thus,

$$CH_{1.425}O_{0.469}N_{0.008928}S_{0.0003908}$$

5.2.1.9.2. Calculation of Stoichiometric Air-Fuel Ratio

The minimum amount of air needed for the complete combustion of a fuel is called the stoichiometric or theoretical air. The stoichiometric ratio is the perfect ideal fuel ratio where the chemical mixing proportion is correct.

A combustion process is complete if all the carbon in the fuel burns to CO_2, all the hydrogen burns to H_2O, and the sulfur (if any) burns to SO_2. That is, all the combustion components of a fuel are burned to completion during a complete combustion process.

Let's now calculate the stoichiometric air-fuel ratio. The formula weight of the wood biomass fuel, or, as written when calcualting the chemical formula, the mass per mole of carbon, including ash and moisture, is

$12\times1 + 1\times1.425 + 16\times0.469 + 14\times0.008928 + 32\times0.0003908 + 0.1875 + 3.75 = 25.00$ gm/mol C

As a result, the molar mass of the wood biomass is 25.00 gm/mol C. In addition, molar mass of the wood biomass is 100.00 gm/mol of fuel for 4.00 moles of Carbon.

We may write the combustion stoichiometry for the above chemical formula as follows:

$$CH_{1.425}O_{0.469}N_{0.008928}S_{0.0003908} + \alpha(O_2 + 3.76N_2) \rightarrow CO_2 + 0.7125H_2O + 0.0003908SO_2 + (3.76\alpha + 0.004464)N_2$$

Balancing Oxygen gives us:

$0.469 + 2\alpha = 2 + 0.7125 + 0.0003908\times2$

$\alpha = 1.12$.

Thus, the stoichiometric air-fuel ratio is given as $\alpha = 1.12$.

5.2.1.9.3. Calculation of Actual Air-Fuel Ratio

For Log Wood (Stacked-Air Dry: 15 % MC), we can assume Excess Air Ratio (λ) to be between 15 % to 20 %. Let's take it to be 18 %.

Mathematically, we can define the Excess Air Ratio as follows:

Excess Air Ratio (λ):

$$\lambda = \left(\frac{Actual\ Air-Fuel\ Ratio - \text{Stoichiometric Air} - \text{Fuel Ratio}}{\text{Stoichiometric Air} - \text{Fuel Ratio}}\right)\times100$$

$$\lambda = \left(\frac{Actual\ Air-Fuel\ Ratio}{\text{Stoichiometric Air} - \text{Fuel Ratio}} - 1\right)\times100 \quad (5.10)$$

Consequently,

$$Actual\ \text{Air-Fuel Ratio} = \left(1 + \frac{\lambda}{100}\right) \times \text{Stoichiometric Air-Fuel Ratio}$$

$$Actual\ \text{Air-Fuel Ratio} = \left(1 + \frac{18}{100}\right) \times 1.12 = 1.32.$$

Therefore, Actual Air-Fuel Ratio = 1.32.

5.2.1.9.4. Calculation of Combustion Air Ratio (Actual Air-Fuel Ratio by Mass)

Mass of Combustion Air = 1.32 × (32 + 3.76 × 28) = 181.21 gm/mol C.

$$Combustion\ \text{Air Ratio} = \frac{Mass\ \text{of Combustion Air}}{Mass\ of\ Fuel} \quad (5.11)$$

$$Combustion\ \text{Air Ratio} = \frac{181.21\ \text{gm/mol C}}{25.00\ \text{gm/mol C}} = 7.2484.$$

5.2.1.9.5. Determination of Flue Gas Properties

5.2.1.9.5.1. Analysis of Flue Gas Composition

We can now write the actual combustion by substituting 1.32 instead of α as follows:

$$CH_{1.425}O_{0.469}N_{0.008928}S_{0.0003908} + 1.32(O_2 + 3.76N_2) \rightarrow CO_2 + 0.7125H_2O + 0.0003908SO_2 + 4.968N_2$$

Table 5.18: Flue Gas Composition

Flue Gas Composition by Mole	Mole Fractions	Flue Gas Composition by Mass Percentage
CO_2 = 1.0000000 H_2O = 0.7125000 SO_2 = 0.0003908 N_2 = 4.9680000 Total = 6.681000	CO_2 = 0.150 H_2O = 0.107 $SO_2 = 5.850\times10^{-5}$ N_2 = 0.744 Total = 1.000	CO_2 = 22.455 % H_2O = 6.545 % SO_2 = 0.0128 % N_2 = 70.988 % Total = 100.000 %

5.2.1.9.5.2. Calculation of Flue Gas-Fuel Ratio by Mass

$$Flue\ \text{Gas Ratio} = \frac{Mass\ \text{of Flue Gas}}{Mass\ \text{of Fuel}} \quad (5.12)$$

$$Flue\ \text{Gas Ratio} = \frac{195.954\ gm/mol\ C}{25.00\ \text{gm /mol C}} = 7.8382.$$

5.2.1.9.5.3. Calculation of Absolute Humidity of Flue Gas

$$Absolute\ \text{Humidity} = \frac{Kg\ \text{of}\ H_2O}{Kg\ \text{of Flue Gas}} \quad (5.13)$$

$$Absolute\ \text{Humidity} = \frac{12.825\times10^{-3}}{195.954\times10^{-3}} = 0.06545\ \text{kg/kg} = 6.545\ \%.$$

5.2.1.9.5.4. Determination of Density of Flue Gas at Standard Conditions

First of all, we need to assume the standard conditions to be at 25 ^{0}C and 101.3 kPa. By the Lee-Kesler analysis, the compressibility factors at standard conditions for each component of the flue gas are given as follows:

Components of Flue Gas	Compressibility Factors
CO_2	0.995
H_2O	0.957
SO_2	0.984
N_2	1.000

Thus,

$$\rho = \frac{P}{ZR_{Specific}T} \qquad (5.14)$$

Where:

P = Pressure of the gas,

Z = Compressibility Factor

T = Temperature of the gas, and

$R_{Specific}$ = Specific Gas Constant = $\frac{R_U}{M}$

R_U = Universal Gas Constant = 8.315 J/K.mol

M = Molar Mass of Gas

For CO_2:

$$R_{Specific} = \frac{R_U}{M} = \frac{8.315 \text{ J/K.mol}}{0.044\ kg/mol} = 189.00 \text{ J/kg.K.}$$

$$\rho = \frac{P}{ZR_{Specific}T} = \frac{101.325\times10^3 kg/m.s^2}{0.995\times189 \text{ J/kg.K}\times298.15\ K} = 1.807 \text{ kg/m}^3.$$

For H_2O:

$$R_{Specific} = \frac{R_U}{M} = \frac{8.315\ \text{J/K.mol}}{0.018\ kg/mol} = 461.94\ \text{J/kg.K.}$$

$$\rho = \frac{P}{ZR_{Specific}T} = \frac{101.325\times10^3\ kg/m.s^2}{0.957\times461.94\ \text{J/kg.K}\times298.15\ K} = 0.769\ \text{kg/m}^3..$$

For SO_2:

$$R_{Specific} = \frac{R_U}{M} = \frac{8.315\ \text{J/K.mol}}{0.064\ kg/mol} = 129.92\ \text{J/kg.K.}$$

$$\rho = \frac{P}{ZR_{Specific}T} = \frac{101.325\times10^3\ kg/m.s^2}{0.984\times129.92\ \text{J/kg.K}\times298.15\ K} = 2.660\ \text{kg/m}^3.$$

For N_2:

$$R_{Specific} = \frac{R_U}{M} = \frac{8.315\ \text{J/K.mol}}{0.028\ kg/mol} = 296.96\ \text{J/kg.K.}$$

$$\rho = \frac{P}{ZR_{Specific}T} = \frac{101.325\times10^3\ kg/m.s^2}{1.00\times296.96\ \text{J/kg.K}\times298.15\ K} = 1.150\ \text{kg/m}^3.$$

Summary:

Components of Flue Gas	Densities (kg/m^3)	Mole Fractions (mol)
CO_2	*1.807*	*0.150*
H_2O	*0.769*	*0.107*
SO_2	*2.660*	5.850×10^{-5}
N_2	*1.150*	*0.744*

Now,

$$\rho_T = \rho_1 n_1 + \rho_2 n_2 + - - - + \rho_n n_n \quad (5.15)$$

Where:

ρ_T = Density of the Flue Gas,

ρ_n = Density of the Flue Gas component, and

n_n = Mole Fraction of the Flue Gas component

Thus,

Components of Flue Gas	Densities (kg/m^3) (ρ_n)	Mole Fractions of Components (n_n)	$\rho_n n_n$ (kg/m^3)
CO_2	1.807	0.150	0.271
H_2O	0.769	0.107	0.0823
SO_2	2.660	5.850×10^{-5}	0.0001556
N_2	1.150	0.744	0.856
ρ_T (Density of Flue Gas)			1.210

5.2.1.9.5.5. Calculation of SO_2 Emission per Hour at Standard Conditions

We have to firstly calculate the total mass of flue gas emitted per hour to the atmosphere at standard conditions. We already obtained the mass flow rate of wood biomass consumption to be 777.960 kg/h. In addition, mass of flue gas per hour is equal to mass of fuel (wood biomass) per hour multiplied by flue gas ratio. Thus,

$$\textit{Mass} \text{ of Flue Gas per Hour} = \text{Mass of Fuel per Hour} \times \text{Flue Gas Ratio.}$$

$$\textit{Mass} \text{ of Flue Gas per Hour} = 2{,}437.20 \text{ kg/h} \times 7.8382.$$

$$\textit{Mass} \text{ of Flue Gas per Hour} = 19{,}103.26 \text{ kg/h.}$$

To find volume of flue gas emitted per hour at standard conditions:

$$\textit{Volume} \text{ of Flue Gas per Hour} = \frac{\textit{Mass} \text{ of Flue Gas per Hour}}{\textit{Density} \text{ of Flue Gas}} \quad (5.16)$$

$$\textit{Volume} \text{ of Flue Gas per Hour} = \frac{19{,}103.26 \text{ kg/h}}{1.210 \text{ kg/m}^3} = 15{,}787.82 \text{ m}^3 / h.$$

To find mass of SO_2 emitted per hour at standard conditions:

From the flue gas composition by mass percentage, we have already known the mass percentage of SO_2 to be 0.0128 %. Thus,

$$Mass \text{ of } SO_2 \text{ Emitted per Hour} = 0.0128 \text{ \% of Mass of Flue Gas Emitted per Hour.}$$

$$Mass \text{ of } SO_2 \text{ Emitted per Hour} = 0.0128 \text{ \% of } 19{,}103.26 \text{ kg/h.}$$

$$Mass \text{ of } SO_2 \text{ Emitted per Hour} = 2.45 \text{ kg/h} = 2450 \text{ gm/h.}$$

To find emission of SO_2 per hour to atmosphere at standard conditions:

$$Emission \text{ of } SO_2 \text{ per Hour} = \frac{Mass \text{ of } SO_2 \text{ per Hour}}{Total \text{ Volume of Flue Gas Emitted per Hour}} \qquad (5.17)$$

$$Emission \text{ of } SO_2 \text{ per Hour} = \frac{2450 \text{ gm/h}}{15{,}787.82 \text{ m}^3 / h} = 0.155 \text{ gm/m}^3 = 155 \text{ mg/m}^3.$$

5.2.1.9.5.6. Calculation of Ratio of CO_2 Generation (kg/kWh)

$$q_{CO_2} = (\frac{c_f}{h_f}) \times (\frac{C_{CO_2}}{C_m}) \qquad (5.18)$$

Where:

q_{CO_2} = Specific $C0_2$ emission (CO_2 / kWh),

c_f = Specific carbon content in the fuel (kg C/kg Fuel),

h_f = Specific energy content (kWh/kg Fuel) = LHV,

C_{CO_2} = Specific mass Carbon Dioxide (kg/mol CO_2), and

C_m = Specific mass Carbon (kg/mol Carbon).

Now,

$$c_f = \frac{12 \times 10^{-3} \; kg}{25.00 \times 10^{-3} \; kg} = 0.48,$$

h_f = 14.65 MJ/kg = 14650 kJ/kg = 4.0694 kWh/kg, and

$$\frac{C_{CO_2}}{C_m} = \frac{44 \times 10^{-3} \text{ kg}}{12 \times 10^{-3} \text{ kg}} = 3.67.$$

Therefore, $q_{CO_2} = (\frac{0.48}{4.0694 \text{ kWh/kg}}) \times 3.67 = 0.433$ kg/kWh.

5.2.2. Replacement of the Three Selected Motors by Recommended Motors

5.2.2.1. Collected Data for Motors

5.2.2.1.1. Nameplate Data of Three Highly Electric Energy Consuming Motors

5.2.2.1.1.1. Nameplate Data of Hydra-Pulper Mill Drive Motor

Table 5.19: Nameplate Data of Hydra-Pulper Mill Drive Motor

Induction A.C. Motor	
Rated Power Capacity	200hp (149.20 kW)
C-Face	Std Foot Mtd
Speed	980 RPM
Enclose	Open
Frame Size	C585
Voltage/Current	380 V/265 Amp
Efficiency	
Phase	Ø3
Type (Model)	
Serial №	CMP,X332125
Manufacturer	BROOK Motor Corporation
Motor View	Single
Rebate	No
Suitable for VSD	Yes

5.2.2.1.1.2. Nameplate Data of Hydra-Refiner Motor

Table 5.20: Nameplate Data of Hydra-Refiner Motor

Induction A.C. Motor	
Rated Power Capacity	200 hp (149.20 kW)
C-Face	Std Foot Mtd
Speed	970 RPM
Enclose	Open
Frame Size	C584
Voltage/Current	380 V/364 Amp
Efficiency	
Phase	Ø3
Type (Model)	DP (713102)
Serial №	CMP,X332125
Manufacturer	BROOK Motor Corporation
Motor View	Single
Rebate	No
Suitable for VSD	Yes

5.2.2.1.1.3. Nameplate Data of Dryer's Line Shaft Motor

Table 5.21: Nameplate Data of Dryer's Line Shaft Motor

Continuous D.C. Motor	
Rated Power Capacity	500 hp (373 kW)
C-Face	Std Foot Mtd
Speed	1150 RPM
Enclose	Open
Frame Size	
Voltage/Current	500 V/795 Amp
Efficiency	
Phase	Ø3
Model	5K8210661A1B
Serial №	CMP,X332125
Manufacturer	General Motor
Motor View	Multiple
Rebate	No
Suitable for VSD	Yes

5.2.2.1.2. Measured Data of the Three Selected Motors

5.2.2.1.2.1. Measured Values of Voltage, Current and Rotational Speed

5.2.2.1.2.1.1. Measured Values of Hydra-Pulper Mill Drive Motor

Table 5.22: Measured Values of Hydra-Pulper Mill Drive Motor

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Rotational Speed (RPM)	Average Rotational Speed (RPM)
V_1 = 364	366	I_1 = 208.04	208.88	Ω_1 = 1430	1435
V_2 = 368		I_2 = 210.60		Ω_2 = 1440	
V_3 = 366		I_3 = 208.00		Ω_3 = 1435	

5.2.2.1.2.1.2. Measured Values of Hydra-Refiner Motor

Table 5.23: Measured Values of Hydra-Refiner Motor

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Rotational Speed (RPM)	Average Rotational Speed (RPM)
V_1 = 360	362	I_1 = 303.40	305.43	Ω_1 = 1205	1210
V_2 = 365		I_2 = 308.20		Ω_2 = 1215	
V_3 = 361		I_3 = 304.69		Ω_3 = 1210	

5.2.2.1.2.1.3. Measured Values of Dryer's Line Shaft Motor

Table 5.24: Measured Values of Dryer's Line Shaft Motor

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Loaded Rotational Speed (RPM)	Average Loaded Rotational Speed (RPM)	No Load Rotational Speed (RPM)
V_1 = 476	480	I_1 = 563.60	568.80	Ω_1 = 1410	1415	1550
V_2 = 486		I_2 = 574.20		Ω_2 = 1420		
V_3 = 478		I_3 = 568.60		Ω_3 = 1415		

5.2.2.2. Calculation of Efficiencies of the Three Selected Motors

5.2.2.2.1. Calculation of Efficiency of the Hydra-Pulper Mill Drive Motor

Measured Data:

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Rotational Speed (RPM)	Average Rotational Speed (RPM)
$V_1 = 364$	366	$I_1 = 208.04$	208.88	$\Omega_1 = 1430$	1435
$V_2 = 368$		$I_2 = 210.60$		$\Omega_2 = 1440$	
$V_3 = 366$		$I_3 = 208.00$		$\Omega_3 = 1435$	

From the Nameplate, the following additional data can be obtained:

- Nameplate Power = 200 hp = 149.20 kW
- Nameplate Rated Voltage = 380 Volts
- Rated Speed = 980 RPM
- Frequency = 60 Hz
- № of Poles = P = 4

Voltage Compensated Full-Load Slip Method:

$$Load = \frac{Slip}{(S_s - S_r)\times(\frac{V_r}{V})^2}\times 100 \qquad (5.19)$$

Where:

$Load$ = Output power as a % of rated power

Slip = Synchronous Speed - Measured Speed in RPM

S_s = Synchronous Speed = $\frac{120\times f}{P}$, f = Frequency in Hz and P = Number of Poles

S_r = Nameplate Full-Load Speed

V_r = Nameplate Rated Voltage

V = Measured Voltage

$(\frac{V_r}{V})^2$ = Voltage Correction Factor

Source: Motor Challenge: Office of Industrial Technologies, Department of Energy, USA

First of all, the Synchronous Speed must be calculated.

$$S_s = \text{Synchronous Speed} = \frac{120 \times f}{P} = \frac{120 \times 60}{4} = 1800 \text{ RPM.}$$

The following four steps must be followed to calculate efficiency of any A.C. Induction Motor:

1. Calculating Percentage Loading

$$Load = \frac{Slip}{(S_s - S_r) \times (\frac{V_r}{V})^2} \times 100 \leftrightarrow Load = \frac{1800 - 1435}{(1800 - 980) \times (\frac{380}{366})^2} \times 100 = 41.29 \text{ \%.}$$

2. Calculating Three-Phase Power in kW

$$P_i = \text{V} \times \text{I} \times \sqrt{3} \times PF \quad (5.20)$$

Where:

P_i = Three-Phase Power in kW

V = Measured Voltage

I = Measured Current

PF = Power Factor

Thus,

$$P_i = \text{V} \times \text{I} \times \sqrt{3} \times PF = 366 \times 208.88 \times \sqrt{3} \times 0.87 = 115{,}201.42 \text{ W} = 115.20 \text{ kW.}$$

3. Calculating Input Power at Full-Rated Load in kW

$$Load = \frac{P_i}{P_{ir}} \times 100 \leftrightarrow P_{ir} = \frac{P_i}{Load} \times 100 \quad (5.21)$$

Where:

P_i = Three-Phase Power in kW

P_{ir} = Input Power at Full-Rated Load in kW

Load = Percentage Loading

Thus,

$$P_{ir} = \frac{P_i}{Load} \times 100 = \frac{115.20 \; kW}{41.29} \times 100 = 279.00 \text{ kW.}$$

4. Calculating the Efficiency at Full-Rated Load

$$\eta_{FL} = \frac{Nameplate\ Full\ Rated\ \text{kW}}{P_{ir}} \quad (5.22)$$

Where:

η_{FL} = Efficiency at Full Rated Load

Thus,

$$\eta_{FL} = \frac{Nameplate\ Full\ Rated\ \text{kW}}{P_{ir}} \times 100 = \frac{149.20\ \text{kW}}{279.00\ \text{kW}} \times 100 = 53.48\ \% \approx 54\ \%.$$

5.2.2.2.2. Calculation of Efficiency of Hydra-Refiner Motor

Measured Data:

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Rotational Speed (RPM)	Average Rotational Speed (RPM)
V_1 = 360	362	I_1 = 303.40	305.43	Ω_1 = 1205	1210
V_2 = 365		I_2 = 308.20		Ω_2 = 1215	
V_3 = 361		I_3 = 304.69		Ω_3 = 1210	

From the Nameplate, the following additional data can be obtained:

- Nameplate Power = 200 hp = 149.20 kW
- Nameplate Rated Voltage = 380 Volts
- Rated Speed = 970 RPM
- Frequency = 60 Hz
- № of Poles = P = 4

The four steps to find efficiency of an A.C. Induction Motor:

1. Calculating Percentage Loading

$$Load = \frac{Slip}{(S_s - S_r) \times (\frac{V_r}{V})^2} \times 100 \leftrightarrow Load = \frac{1800 - 1210}{(1800 - 970) \times (\frac{380}{362})^2} \times 100 = 64.51\ \%.$$

2. Calculating Three-Phase Power in kW

$$P_i = V \times I \times \sqrt{3} \times PF = 362 \times 305.43 \times \sqrt{3} \times 0.87 = 166{,}609.65\ W = 166.61\ kW.$$

3. Calculating Input Power at Full-Rated Load in kW

$$P_{ir} = \frac{P_i}{Load} \times 100 = \frac{166.61\ kW}{64.51} \times 100 = 258.27\ kW.$$

4. Calculating Efficiency at Full-Rated Load

$$\eta_{FL} = \frac{Nameplate\ Full\ Rated\ \text{kW}}{P_{ir}} \times 100 = \frac{149.20\ \text{kW}}{258.27\ \text{kW}} \times 100 = 57.77\ \% \approx 58\ \%.$$

5.2.2.2.3. Calculation of Efficiency of Dryer's Line-Shaft Motor

This motor is the only Continuous DC Motor from the selected three motors to be replaced.

Measured Data:

Voltage (Volts)	Average Voltage (Volts)	Current (Amps)	Average Current (Amps)	Loaded Rotational Speed (RPM)	Average Loaded Rotational Speed (RPM)	No Load Rotational Speed (RPM)
$V_1 = 476$	480	$I_1 = 563.60$	568.80	$\Omega_1 = 1410$	1415	1550
$V_2 = 486$		$I_2 = 574.20$		$\Omega_2 = 1420$		
$V_3 = 478$		$I_3 = 568.60$		$\Omega_3 = 1415$		

From the Nameplate, the following additional data can be obtained:

- Nameplate Power = 500 hp = 373 kW
- Nameplate Rated Voltage = 500 Volts
- Rated Speed = 1150 RPM
- Frequency = 60 Hz
- № of Poles = P = 4

For Continuous D.C. Motor,

$$P_{input} = \mathrm{V} \times \mathrm{I} \qquad (5.23)$$

Where:

P_{input} = Input Power to the Motor

V = Measured Voltage

I = Measured Current

Thus,

$P_{input} = \mathrm{V} \times \mathrm{I} = 480 \times 568.80 = 273{,}024$ W = 273.024 kW.

And,

$$P_{output} = \tau_{output} \times \Omega \qquad (5.24)$$

Where:

P_{output} = Output Power of the Shaft of the Motor

τ_{output} = Output Torque of the Shaft of the Motor

Ω = Rotational Speed of the Shaft of the Motor (Measured Rotational Speed)

It is known that

$$P_{rated} = \tau_{rated} \times \Omega_{rated} \qquad (5.25)$$

Where:

P_{rated} = Nameplate Rated Power

τ_{rated} = Nameplate Rated Torque

Ω_{rated} = Nameplate Rated Rotational Speed (in rad/s)

Thus,

$$\tau_{rated} = \frac{P_{rated}}{\Omega_{rated}} = \frac{373 \text{ kW}}{(1150 \times \frac{2\pi}{60}) rad / \mathrm{s}} = 3.097 \text{ kN.m.}$$

In addition to the above,

The no load speed of the shaft of a D.C. motor means the speed at which the motor runs without a mechanical load connected to its rotor shaft. Thus, the no load speed occurs only when the torque of the shaft is zero.

It is now possible to find the stall torque (τ_s) by using the slope formula because torque and rotational speed have linear relationship. The stall torque occurs when rotational speed is zero. Thus, the following three coordinates can be taken from the linear relationship between torque and rotational speed.

Rotational Speed (RPM)	1150	1550	0
Torque (kN.m)	3.097	0	τ_s

$$Slope = \frac{0-3.097}{1550-1150} = \frac{\tau_s - 0}{0-1550} \leftrightarrow \tau_s = 12.00 \text{ kN.m.}$$

Now, it is possible to plot the continuous D.C. motor torque vs rotational speed graph by using MATLab script as follows:

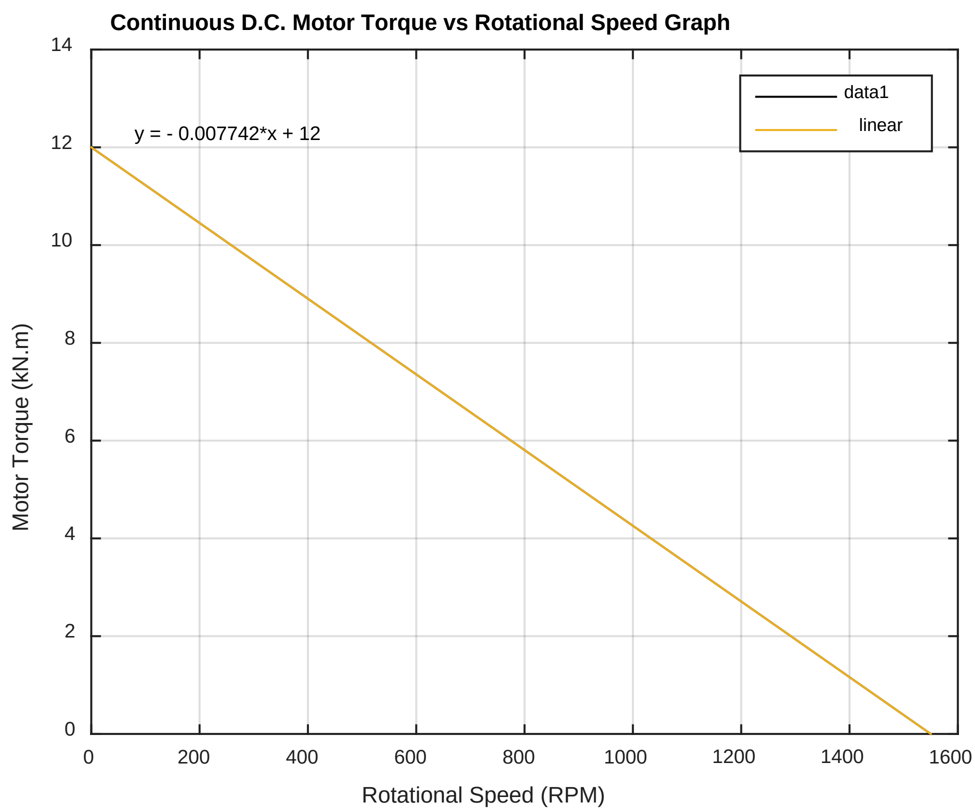


Figure 5.6: Graph of Continuous D.C. Motor Torque vs Rotational Speed

From the above graph, torque (τ) is obtained as a function of rotational speed (Ω) and it is expressed as follows:

$$\tau = -0.007742\ \Omega + 12$$

Remember that the torque is obtained in kN.m if and only if the rotational speed is used in RPM.

To find the Output Power as a function of Rotational Speed (Ω):

$$P_{output} = \tau_{output} \times \Omega = (-0.007742\Omega + 12) \times (\frac{2\pi}{60})\Omega = -0.000810732\Omega^2 + 1.25664\Omega..$$

To get output power in kW, the rotational speed must be changed into rad/s. That is the reason why $\frac{2\pi}{60}$ is used in the above calculation. Now, the output power is obtained in kW if and only if the rotational speed is used in PRM because $\frac{2\pi}{60}$ is included in the calculation.

It is now possible to express the output power as a function of Rotational Speed by the following equation: $P_{output} = -0.000810732\Omega^2 + 1.25664\Omega.$

Again, it is now possible to plot output power vs rotational speed curve as follows:

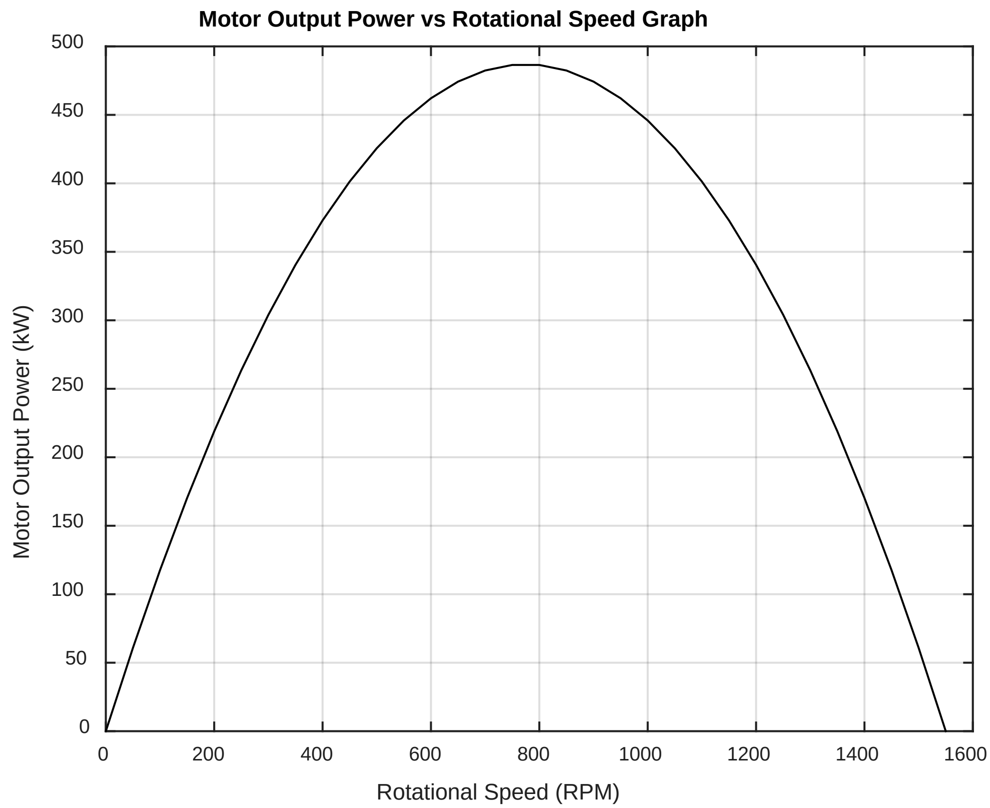


Figure 5.7: Graph of Continuous D.C. Motor Power Output vs Rotational Speed

The maximum output power exists when $\frac{dP_{output}}{d\Omega} = 0$..

$$\frac{dP_{output}}{d\Omega} = \frac{d}{d\Omega}(-0.000810732\Omega^2 + 1.25664\Omega) = -0.000810732\times 2\Omega + 1.25664$$
$$= -0.001621464\Omega + 1.25664 = 0 \leftrightarrow \Omega = 775 \text{ RPM}.$$

When $\Omega = 775$ RPM, $(P_{output})_{max} = 486.95$ kW ≈ 487 kW.

To find the Output Power when $\Omega = 1415$ RPM:

$$P_{output} = -0.000810732\Omega^2 + 1.25664\Omega = -0.000810732\times(1415)^2 + 1.25664\times 1415 = 154.88 \text{ kW}.$$

To find Efficiency of Dryer's Line-Shaft Motor:

$$\eta = \frac{P_{output}}{P_{input}}\times 100 = \frac{154.880 \text{ kW}}{273.024 \text{ kW}}\times 100 = 56.73\ \% \approx 57\ \%.$$

Summary:

Table 5.25: Efficiencies of the Three Selected Motors

Motor	Type	Efficiency
Hydra-Pulper Mill Drive Motor	Induction A.C. Motor	54 %
Hydra-Refiner Motor	Induction A.C. Motor	58 %
Dryer's Line-Shaft Motor	Continuous D.C. Motor	57 %

5.2.3. Economic Feasibility Analysis for Investment of Wood Biomass Boiler and Recommended Motors

5.2.3.1. Economic Feasibility Analysis for Investment of Wood Biomass Boiler

5.2.3.1.1. Calculation of Total Annual Operational and Maintenance Cost of Wood Biomass Boiler

We have the following format for operational and maintenance cost:

Items	Costs	%
Raw Materials , Utilities, Inputs and Related		
Labor Direct		
Labor Overheads		
Land Lease		
Equipment Depreciation		
Maintenance and Repair		
Total		

a) Calculation of Raw Material, Utilities, Inputs and Related Cost

i. Calculation of Total Annual Diesel Fuel Consumption Cost for Wood Biomass Supplementation

To Calculate Total Wood Biomass Required in a Year:

We already obtained the mass flow rate of wood biomass consumption = 2,437.20 kg/h in order to produce the same amount of steam by using the same amount of feed water like those used for electric steam boiler under the same pressure and temperature conditions. And, we also already know that the average annual working hours = 2,124. Thus, the average annual wood biomass consumption = 2,437.20 kg/h × 2,124 hours = 5,176,612.80 kg.

Table 5.26: Total Annual Diesel Fuel Consumption Cost for Wood Biomass Supplementation

Items	Average Amounts
Total Wood Biomass Required in a Year	5,176,612.80 kg
Total Wood Biomass Loaded in a Trip	24.65 tons = 24,650.00 kg
Total Number of Round-Trips Required in a Year	210
Total Number of Months Required for Service of the Truck in a Year	10
Total Average Number of Trips Required in a Month	24 (1 Trip in a Day)
Location-Place	Aris
Location-Distance	250 km
Total Round-Trip Distance	250×2 = 500 km
Average Speed of Sinotruk in Ethiopia	62.50 km/h
Fuel Consumption of Sinotruk in Ethiopia	30 Liters per 100 km
Diesel Fuel Consumption of Sinotruk in Ethiopia on Round-Trip	150 Liters
Total Diesel Fuel Consumption of Sinotruk in Ethiopia for Round-Trip in a Year	150×210 = 31,500 Liters
Diesel Fuel Cost per Liter (May, 2016)	14.16 Birr
Annual Total Cost of Diesel Fuel Consumption for Round-Trips to Supply Wood	31,500×14.16 = 446,040 Birr

ii. Calculation of Total Annual Diesel Fuel Consumption Cost for Ash Disposing

To Calculate Total Ash to be Disposed in a Year:

We already know that there is 0.1875 gm Ash/mol Carbon in wood biomass or 0.1875 gm Ash/25.00 gm wood biomass. In kg, there is 1.875×10^{-4} kg Ash/0.025 kg wood biomass. Therefore, there exists 38,824.60 kg Ash in 5,445,720.00 kg wood biomass.

Table 5.27: Total Annual Diesel Fuel Consumption Cost for Ash Disposing

Items	Average Amounts
Total Ash to be Disposed in a Year	38,824.60 kg
Total Ash to be Disposed in a Trip	3,880.00 kg
Total Number of Round-Trips Required in a Year	10
Location-Distance	50 km
Total Round-Trip Distance	50×2 = 100 km
Fuel Consumption of the Truck to Dispose the Ash	30 Liters per 100 km
Diesel Fuel Consumption to Dispose the Ash on Round-Trip	30 Liters
Total Diesel Fuel Consumption to Dispose the Ash in a Year	30×10 = 300 Liters
Diesel Fuel Cost per Liter (May, 2016)	14.16 Birr
Annual Total Cost of Diesel Fuel Consumption for Round-Trips to Dispose Ash	300×14.16 = 4,248 Birr

iii. Calculation of Total Annual Loading and Unloading Cost for Wood Biomass and Ash Disposing

Table 5.28: Total Annual Loading and Unloading Cost for Wood Biomass and Ash Disposing

Costs	Average Amounts
Monthly Salary for Two Drivers of Heavy Truck	1500 ×2 = 3,000 Birr
Monthly Salary for Four Labors	850×4 = 3,400 Birr
Annual Total Loading and Unloading Cost for Wood and Ash	6,400×12 = 76,800 Birr

Thus, we can now get the raw material, utilities, inputs and related cost as follows:

Table 5.29: Raw Material, Utilities, Inputs and Related Cost

Items	Average Amounts
Total Annual Cost of Diesel Fuel Consumption for Round-Trips to Supply Wood	446,040.00 Birr
Total Annual Cost of Diesel Fuel Consumption for Round-Trips to Dispose Ash	4,248.00 Birr
Total Annual Loading and Unloading Cost for Wood and Ash	76,800.00 Birr
Total Annual Electricity Cost for Pumps and Motors	110,000.00 Birr
Total Wood Biomass Required in a Year	5,176,612.80 kg
Price of 1 kg of Wood Biomass in the Selected Forest Area in Ethiopia	0.40 Birr (From Market Surveying)
Total Annual Cost of Wood Biomass	2,070,645.12 Birr
Total Annual Cost for Water Management	96,000.00 Birr
Total Annual Cost for Sewer	48,000.00 Birr
Total	2,851,733.12 Birr

b) Calculation of Total Annual Labor Direct Cost

Table 5.30: Total Annual Labor Direct Cost for Wood Biomass Boiler

Items	Average Amounts
№ of Labor Employs for the Boiler	13
Average Salary of an Employ	3,000.00 Birr
Annual Labor Direct Cost	468,000.00 Birr

c) Calculation of Total Annual Labor Overheads (Especially Insurance and Telephone) Cost

Table 5.31: Total Annual Labor Overheads Cost for Wood Biomass Boiler

Items	Average Cost (Birr)
Insurance Cost for the Boiler (0.6 % of the FOB Price of the Boiler)	108,016.20
Telephone Cost	36,000.00
Total	144,016.20

d) Calculation of Total Annual Depreciation Expense

i. Calculation of Total Annual Depreciation Expense of Trucks

First of all, the salvage value must be calculated. We have the following formula for salvage value calculation:

$$S = P(1-i)^{Y} \qquad (5.26)$$

Where:

S = Salvage Value. It isn't perfect, but it is an estimate at the time of purchase.

P = Original Price

i = Nominal Depreciation Rate

Y = Age in Years

Nominal Depreciation Rate in Ethiopia

Table 5.32: Nominal Depreciation Rate in Ethiopia

Asset	Rate
Buildings & Structures	5 %
Automobiles, Motors & Machineries	20 %
Intangible Assets	10 %
Computers, Information Systems & Software Products	25 %

Source: National Bank of Ethiopia

The following conditions should be taken into consideration to get the salvage value of the trucks:

- Two Sinotruk vehicles are required to be purchased. The price of each of them is nearly 1,400,000 Birr.
- Based on the above table, the nominal depreciation rate for automobiles in Ethiopia is 20 %.
- Lifespan on average expected mileage of Sinotruk vehicles is 5 years at least under normal condition for long distance service. (Source: Sinotruk Hubei Huawin Imp. & Exp. Co., Ltd.)

Let's now calculate salvage value for Sinotruk vehicles:

Table 5.33: Salvage Value for Sinotruk Vehicles

Items	Average Amounts
Original Price (P) for the Single Vehicle (in Birr)	1,400,000
Depreciation Rate (i) (in Decimal Form)	0.20
Lifespan (Y) (in Years)	5
Salvage Value (S) for the Single Vehicle (in Birr) ($S = P(1-i)^Y$)	458,752.00
Number of Vehicles	2
Total Salvage Value for the Two Vehicles (in Birr)	917,504.00

We can now calculate total annual depreciation expense for the two vehicles as follows:

$$Annual\ \text{Depreciation Expense} = \frac{Cost\ \text{of Asset} - Salvage\ \text{Value}}{Estimated\ \text{Useful Lifespan}} \qquad (5.27)$$

Table 5.34: Total Annual Depreciation Expense for the Two Sinotruk Vehicles

Items	Value
Total Cost of Asset for the Two Vehicles (in Birr)	1,400,000 × 2 = 2,800,000
Total Salvage Value for the Two Vehicles (in Birr)	917,504.00
Estimated Useful Lifespan (in Year)	5
$Annual\ \text{Depreciation Expense} = \frac{Cost\ \text{of Asset} - Salvage\ \text{Value}}{Estimated\ \text{Useful Lifespan}}$ (in Birr)	376,499.20

ii. Calculation of Total Annual Depreciation Expense of Wood Biomass Boiler

Table 5.35: Total Annual Depreciation Expense for Wood Biomass Boiler

Items	Average Amounts
Original Cost of the Asset (Wood Biomass Boiler) (P) (in Birr)	18,002,700.00
Depreciation Rate (i) (in Decimal Form)	0.20
Lifespan (Y) (in Years)	25
Salvage Value (S) for the Boiler ($S = P(1-i)^Y$) (in Birr)	68,012.28
$Annual\ \text{Depreciation Expense} = \frac{Cost\ \text{of Asset} - Salvage\ \text{Value}}{Estimated\ \text{Useful Lifespan}}$ (in Birr)	717,387.51

Now, we can calculate total annual depreciation expense as follows:

Table 5.36: Total Annual Depreciation Expense for the Two Vehicles and Wood Biomass Boiler

Items	Average Costs (Birr)
Annual Depreciation Expense for the two vehicles	376,499.20
Annual Depreciation Expense for the Boiler	717,387.51
Total	1,093,886.71

e) Calculation of Total Annual Maintenance and Repair Cost

i. Maintenance Cost of Wood Biomass Boiler

Table 5.37: Total Annual Maintenance Cost of Wood Biomass Boiler

Annual Maintenance Costs	Average Costs (Birr)
Maintenance & Lubrication	60,000.00
Major Repairs (Annualized)	70,000.00
Total Annual Maintenance Cost of the Wood Biomass Boiler	130,000.00

ii. Maintenance Cost of Sinotruk Vehicles

Table 5.38: Total Annual Maintenance Cost of Sinotruk Vehicles

Annual Maintenance Costs	Average Costs (Birr)
Maintenance, Lubrication & Repair	15,000.00
Spare Parts including Tires	60,000.00
Total Annual Maintenance Cost of Sinotruk Vehicles	75,000.00

Now, we can calculate total annual maintenance and repair cost as follows:

Table 5.39: Total Annual Maintenance and Repair Cost

Items	Average Costs (Birr)
Total Annual Maintenance Cost of the Wood Biomass Boiler	130,000.00
Total Annual Maintenance Cost of the Trucks	75,000.00
Total	205,000.00

Finally, we can calculate total annual operational and maintenance cost for wood biomass boiler as follows:

Table 5.40: Total Annual Operational and Maintenance Cost for Wood Biomass Boiler

Items	Costs (Birr)	%
Raw Materials , Utilities, Inputs and Related	2,851,733.12	59.88%
Labor Direct	468,000.00	9.83%
Labor Overheads	144,016.20	3.02%
Land Lease	0.00	0.00%
Equipment Depreciation	1,093,886.71	22.97%
Maintenance and Repair	205,000.00	4.30%
Total	4,762,636.03	100.0 %

5.2.3.1.2. Calculation of Total Annual Operational and Maintenance Cost of Electric Steam Boiler

a) Calculation of Raw Material, Utilities, Inputs and Related Cost

As the case of wood biomass boiler, we can use the following tabular data to get the raw material, inputs and related costs for electric steam boiler:

Thus, we can now get raw material, utilities, inputs and related cost as follows:

Table 5.41: Raw Material, Utilities, Inputs and Related Cost

Items	Average Amounts
Average Electric Steam Boiler Input Power	8,676.32 kW
Average Annual Working Hours of the Electric Steam Boiler	2,124.00 hours
Average Annual Electric Energy Consumption of the Electric Steam Boiler	18,428,492.98 kWh
Electric Tariff of the Ethiopian Electric Power Corporation (EEPCo)	0.4086 Birr/kWh
Average Annual Cost of Energy Consumption of the Electric Steam Boiler	7,529,882.23 Birr
Total Annual Cost for Water Management	96,000.00 Birr
Total Annual Cost for Sewer	48,000.00 Birr
Total	7,673,882.23 Birr

b) Calculation of Total Annual Labor Direct Cost

Table 5.42: Total Annual Labor Direct Cost for Electric Steam Boiler

Items	Average Amounts
№ of Labor Employs for the Boiler	10
Average Salary of an Employ	3,000.00 Birr
Total Annual Labor Direct Cost	360,000.00 Birr

c) Calculation of Total Annual Labor Overheads (Especially Insurance and Telephone) Cost

Table 5.43: Total Annual Labor Overheads Cost for Electric Steam Boiler

Items	Average Cost (Birr)
Insurance Cost for the Boiler (0.6 % of the FOB Price of the Boiler) FOB Price of the 6 MW Boiler = 7.80 Million Birr FOB Price of the 3 MW Boiler = 3.52 Million Birr	67,920.00
Telephone Cost	24,000.00
Total	91,920.00

d) To Calculate Total Annual Depreciation Expense for Electric Steam Boiler

Table 5.44: Total Annual Depreciation Expense for Electric Steam Boiler

Items	Average Amounts
Original Cost of the Asset (Electric Steam Boilers) (P) (in Birr)	11,320,000.00
Depreciation Rate (i) (in Decimal Form)	0.20
Lifespan (Y) (in Years)	25
Salvage Value (S) for the Boiler ($S = \text{P}(1-\text{i})^{Y}$) (in Birr)	42,765.75
$Annual \text{ Depreciation Expense} = \frac{Cost \text{ of Asset} - Salvage \text{ Value}}{Estimated \text{ Useful Lifespan}}$ (in Birr)	451,089.37

e) Calculation of Total Annual Maintenance and Repair Cost for Electric Steam Boiler

Table 5.45: Total Annual Maintenance and Repair Cost for Electric Steam Boiler

Annual Maintenance Costs	Average Costs (Birr)
Maintenance and Check-Up	20,000.00
Major Repairs (Annualized)	60,000.00
Total Annual Maintenance Cost of the Electric Steam Boiler	80,000.00

Finally, we can calculate total annual operational and maintenance cost for electric steam boiler as follows:

Table 5.46: Total Annual Operational and Maintenance Cost for Electric Steam Boiler

Items	Costs (Birr)	%
Raw Materials , Utilities, Inputs and Related	7,673,882.23	88.65%
Labor Direct	360,000.00	4.16%
Labor Overheads	91,920.00	1.06%
Land Lease	0.00	0.00%
Equipment Depreciation	451,089.37	5.21%
Maintenance and Repair	80,000.00	0.92%
Total	8,656,891.60	100.00 %

5.2.3.1.3. Calculation of Initial Investment Cost of Wood Biomass Boiler

a) Calculation of Total Cost of Wood Biomass Boiler

We have to firstly calculate freight and insurance costs for wood biomass boiler as follows:

i. Calculation of Freight Cost of Wood Biomass Boiler

Figure 5.8: Transporation of Wood Biomass Boiler from Company to Port

Table 5.47: Freight Cost for Wood Biomass Boiler

Method of Shipping	Ocean
Locations: • Origin Port • Destination Port • Commodity • Commodity Value (FOB Boiler Cost)	 • Sunderland, United Kingdom • Djibouti, Djibouti and then Wenji • Machinery (Boiler) • 830,000.00 USD (18,002,700.00 Birr)
Load: • Load Type • Container Type • Material Handling	 • Full Container Load • 40 ft • Refrigerated or Environmentally Controlled
Current Market Rate for Freight Cost	5,228.54 USD (113,407.03 Birr)

ii. Calculation of Insurance Cost for Shipping of Wood Biomass Boiler

Table 5.48: Insurance Cost for Shipping of Wood Biomass Boiler

Items	Costs (Birr)
FOB Cost of Boiler	18,002,700.00
Insurance Cost of Boiler (4% of FOB Cost)	720,108.00

iii. Calculation of Total Cost (Duty Paying Value) of Wood Biomass Boiler

Then, we can now calculate total cost of boiler (duty paying value) as follows:

Table 5.49: Total Cost (Duty Paying Value) of Wood Biomass Boiler

Items	Costs (Birr)
FOB Cost	18,002,700.00
Freight Cost	113,407.03
Insurance Cost	720,108.00
Total Cost of Boiler	18,836,215.03

Notation:

Machinery and equipment are 100 % exempted from payments of customs duties and other taxes based on the Investment Incentives in Ethiopia. Source: Customs Proclamation № 859/2014.

b) Calculation of Installation, Commissioning and Training (Mechanical and Electrical) Cost

Duration: 15 days

Firstly, we have to calculate total team workers cost for 15 days as follows:

Table 5.50: Total Team Workers Cost for Installation, Commissioning and Training of Wood Biomass Boiler

Members of Team Workers	№	Payments per Day (Birr)	Payments for 15 Days (Birr)
Mechanical Engineers from United Kingdom	2	2,169.00×2 = 4,338.00	65,070.00
Electrical Engineers from United Kingdom	2	2,169.00×2 = 4,338.00	65,070.00
Technicians from Ethiopia	2	140.00×2 = 280.00	4,200.00
Process Optimizers from Ethiopia	2	140.00×2 = 280.00	4,200.00
Unskilled Labors from Ethiopia	10	70.00×10 = 700.00	10,500.00
Total	18	9,936.00	149,040.00

Then, we can now calculate installation, commissioning and training cost as follows:

Table 5.51: Total Installation, Commissioning and Training Cost for Wood Biomass Boiler

Items	Average Costs (Birr)
Round Trip Travel Air Tickets Cost for the 4 Engineers	22,275.63×4 = 89,102.52
Total Team Workers Cost	149,040.00
Accommodation Cost for the 4 Engineers in Adama	760.00×4×15 = 45,600.00
Food and Drink Cost for the 4 Engineers in Adama	1,300×4×15 = 78,000.00
Total	361,742.52

c) Calculation of Initial Investment Cost of Wood Biomass Boiler

Finally, we can calculate initial investment cost of wood biomass boiler as follows:

Table 5.52: Initial Investment Cost of Wood Biomass Boiler

Items	Costs (Birr)
Total Cost of the Boiler	18,836,215.03
Building and Civil Work Cost (5000 Birr/m^2) Boiler Room (144 m^2) Wood Room (100 m^2) Ash Room (25 m^2)	 720,000.00 500,000.00 125,000.00
Installation (Erection), Commissioning and Training Cost	361,742.52
Land Lease Cost	0.00
Total	20,542,957.55

5.2.3.1.4. Calculation of Payback Period for Investment of Wood Biomass Boiler

We ought to first find net annual saving for using wood biomass boiler.

$$Net\ \text{Annual Saving} = \text{AOMC}_{Electric\ \text{Steam Boiler}} - AOMC_{Wood\ \text{Biomass Boiler}} \qquad (5.28)$$

Where:

AOMC = Annual Operational & Maintenance Cost

Thus,

$$Net\ \text{Annual Saving} = \text{AOMC}_{Electric\ \text{Steam Boiler}} - AOMC_{Wood\ \text{Biomass Boiler}}$$

$$Net\ \text{Annual Saving} = 8{,}656{,}891.60\ \text{Birr} - 4{,}762{,}636.03\ \text{Birr}$$

$$\text{Net Annual Saving} = 3{,}894{,}255.57\ \text{Birr} = 179{,}541.53\ \text{USD.}$$

Now, we can calculate Payback Period (years) as follows:

$$Payback\ \text{Period (years)} = \frac{Initial\ \text{Investment Cost}}{Net\ \text{Annual Saving}} \qquad (5.29)$$

Source: Energy Management, Supply & Conservation, Dr. Clive Beggs, Butterworth Heinemann

Thus,

$$Payback\ \text{Period (years)} = \frac{20{,}542{,}957.55\ \text{Birr}}{3{,}894{,}255.57\ \text{Birr/year}} = 5.28\ \text{Years} = 5\ \text{Years \& 3 Months.}$$

We can take the payback period to be nearly 5 years.

5.2.3.1.5. Calculation of Net Present Value for Investment of Wood Biomass Boiler

First of all, we have to determine the discount rate for Ethiopia. In the long-term, the Ethiopia inflation rate will be projected to trend around 6.00 percent in 2020 according to central statistical agency of Ethiopia. Considering interest rate, it will remain to be 5.00 percent in 2020 according to national bank of Ethiopia. Therefore, Inflation Rate ≈ 6 % and Interest Rate ≈ 5 % for Ethiopia. By the Fisher equation,

$$i = \frac{1+r}{1+p} - 1 \approx r - p \ \leftrightarrow\ \text{r} \approx \text{i} + \text{p.} \qquad (5.30)$$

Where:

r = Nominal Interest Rate (Discount Rate),

i = Real Interest Rate, and

p = Inflation Rate.

Therefore, the discount rate for Ethiopia = r ≈ 11 %.

Table 5.53: Economic Flow of the Wood Biomass Boiler Investment

Year	Net Annual Savings (Birr) C_t	Present Value Factor $V^t = (1+r)^{-t}$	Present Value (Discounted Energy Cost Savings) (Birr) $PV = \frac{C_t}{(1+r)^t}$
0	-20,542,957.55	1.00	-20,542,957.55
1	3,894,255.57	0.90	3,504,830.01
2	3,894,255.57	0.81	3,154,347.01
3	3,894,255.57	0.73	2,842,806.57
4	3,894,255.57	0.66	2,570,208.68
5	3,894,255.57	0.59	2,297,610.79
6	3,894,255.57	0.54	2,102,898.01
7	3,894,255.57	0.48	1,869,242.67
8	3,894,255.57	0.43	1,674,529.90
9	3,894,255.57	0.39	1,518,759.67
10	3,894,255.57	0.35	1,362,989.45
11	3,894,255.57	0.32	1,246,161.78
12	3,894,255.57	0.29	1,129,334.12
13	3,894,255.57	0.26	1,012,506.45
14	3,894,255.57	0.23	895,678.78
15	3,894,255.57	0.21	817,793.67
16	3,894,255.57	0.19	739,908.56
17	3,894,255.57	0.17	662,023.45
18	3,894,255.57	0.15	584,138.34
19	3,894,255.57	0.14	545,195.78
20	3,894,255.57	0.12	467,310.67
21	3,894,255.57	0.11	428,368.11
22	3,894,255.57	0.10	389,425.56
23	3,894,255.57	0.09	350,483.00
24	3,894,255.57	0.08	311,540.45
25	3,894,255.57	0.07	272,597.89
Net Present Value (NPV)			12,253,468.52

5.2.3.2. Economic Feasibility Analysis for Investment of Recommended Motors

5.2.3.2.1. Calculation of Net Annual Savings Cost

$$S = \text{hp} \times 0.746 \times \left[\frac{1}{\eta_1} - \frac{1}{\eta_2}\right] \times H \times C \qquad (5.31)$$

Where:

S = Net Annual Savings Cost,

hp = Rated Power,

H = Annual Operating Time,

C = Cost of Electrical Energy per kWh,

η_1 = Efficiency expressed as a Decimal for Lower Efficiency Value of the two being Considered, &

η_2 = Efficiency, Higher Value.

Source: Energy-Efficient Electric Motors & their Applications by H.E. Jordan

a) Calculation of Net Annual Savings Cost for Dryer's Line-Shaft Motor

Items	Old Motor	Recommended Motor
Horsepower	500	500
Efficiency	57 %	96 %
Annual Operating Time	2,124 hours	2,124 hours
Energy Cost per kWh	0.4086 Birr	0.4086 Birr

We have the following formula:

$$S = \text{hp} \times 0.746 \times \left[\frac{1}{\eta_1} - \frac{1}{\eta_2}\right] \times H \times C$$

Thus,

$$S = 500 \text{ hp} \times 0.746 \ \frac{kW}{hp} \times \left[\frac{1}{0.57} - \frac{1}{0.96}\right] \times 2124 \text{ hr} \times 0.4086 \ \frac{Birr}{kWh}$$

S = 230,717.33 Birr.

b) Calculation of Net Annual Savings Cost for Hydra-Pulper Mill Drive Motor

Items	Old Motor	Recommended Motor
Horsepower	200	200
Efficiency	54 %	96 %
Annual Operating Time	2,124 hours	2,124 hours
Energy Cost per KWh	0.4086 Birr	0.4086 Birr

Now,

$$S = \text{hp} \times 0.746 \times \left[\frac{1}{\eta_1} - \frac{1}{\eta_2}\right] \times H \times C$$

Thus,

$$S = 200 \text{ hp} \times 0.746 \ \frac{kW}{hp} \times \left[\frac{1}{0.54} - \frac{1}{0.96}\right] \times 2124 \text{ hr} \times 0.4086 \ \frac{Birr}{kWh}$$

S = 104,907.37 Birr.

c) Calculation of Net Annual Savings Cost for Hydra-Refiner Motors

Items	Old Motor	Recommended Motor
Horsepower	200	200
Efficiency	58 %	96 %
Annual Operating Time	2,124 hours	2,124 hours
Energy Cost per KWh	0.4086 Birr	0.4086 Birr

Now,

$$S = \text{hp} \times 0.746 \times \left[\frac{1}{\eta_1} - \frac{1}{\eta_2}\right] \times H \times C$$

Thus,

$$S = 200 \text{ hp} \times 0.746 \ \frac{kW}{hp} \times \left[\frac{1}{0.58} - \frac{1}{0.96}\right] \times 2124 \text{ hr} \times 0.4086 \ \frac{Birr}{kWh}$$

S = 88,370.25 Birr.

There are two A.C. Motors for the Hydra-Refiner.

Thus, the Total Savings for the Hydra-Refiner = 88,370.25 ×2 = 176,740.50 Birr.

d) Calculation of Net Annual Savings Cost for Investment of Recommended Motors

Now, we can calculate Net Annual Savings Cost as follows:

Table 5.54: Net Annual Savings Cost for Investment of Recommended Motors

Motors	Costs (Birr)	Costs (USD)
Dryer's Line-Shaft Motor	230,717.33	10,637.04
Hydra-Pulper Mill Drive Motor	104,907.37	4,836.67
Hydra-Refiner Motors	176,740.50	8,148.48
Total	512,365.20	23,622.19

5.2.3.2.2. Calculation of Payback Period for Investment of Recommended Motors

a) Calculation of Investment Cost for Recommended Motors

Table 5.55: Investment Cost for Recommended Motors

Motors	FOB Price (Birr)	Freight Cost (Birr)	Insurance Cost 4 % of FOB Price (Birr)	Cost of Motor (Birr)
Dryer's Line-Shaft Motor	1,626,750.00	79,986.32	65,070.00	1,771,806.32
Hydra-Pulper Mill Drive Motor	336,195.00	79,986.32	13,447.80	429,629.12
Hydra-Refiner Motors	672,390.00	159,972.64	26,895.60	859,258.24
Total Cost of the Recommended Motors				3,060,693.68

b) Calculation of Investment Cost for Old Motors

Table 5.56: Investment Cost for Old Motors

Motors	FOB Price (Birr)	Freight Cost (Birr)	Insurance Cost 4 % of FOB Price (Birr)	Cost of Motor (Birr)
Dryer's Line-Shaft Motor	211,314.83	10,390.22	8,452.59	230,157.64
Hydra-Pulper Mill Drive Motor	43,671.73	10,390.22	1,746.87	55,808.82
Hydra-Refiner Motors	87,343.46	20,780.44	3,493.74	111,617.64
Total Cost of the Recommended Motors				397,584.10

c) Calculation of Payback Period for Investment of Recommended Motors

$$PBP = \frac{CD}{S} \qquad (5.32)$$

Where:

PBP = Payback Periods in years,

S = Net Annual Savings, &

CD = Cost Difference between the Recommended Motors Investment & the Old Motors Investment.

Source: Energy-Efficient Electric Motors & their Applications by H.E. Jordan

Thus,

$$PBP = \frac{CD}{S} = \frac{3,060,693.68 \text{ Birr} - 397,584.10 \text{ Birr}}{512,365.20 \text{ Birr/year}} = 5.20 \text{ years} \approx 5 \text{ years \& 2 months.}$$

5.2.3.2.3. Calculation of Net Present Value for Investment of Recommended Motors

Considerations:

- Lifespan for the Investment of the Recommended Motors is 20 years.
- Discount Rate in Ethiopia is 11 %.

Table 5.57: Economic Flow of Investment of Recommended Motors

Year	Net Annual Savings (Birr) C_t	Present Value Factor $V^t = (1+r)^{-t}$	Present Value (Discounted Energy Cost Savings) (Birr) $PV = \frac{C_t}{(1+r)^t}$
0	-3,060,693.68	1.00	-3,060,693.68
1	512,365.20	0.90	461,128.68
2	512,365.20	0.81	415,015.81
3	512,365.20	0.73	374,026.60
4	512,365.20	0.66	338,161.03
5	512,365.20	0.59	302,295.47
6	512,365.20	0.54	276,677.21
7	512,365.20	0.48	245,935.30
8	512,365.20	0.43	220,317.04
9	512,365.20	0.39	199,822.43
10	512,365.20	0.35	179,327.82
11	512,365.20	0.32	163,956.86
12	512,365.20	0.29	148,585.91
13	512,365.20	0.26	133,214.95
14	512,365.20	0.23	117,844.00
15	512,365.20	0.21	107,596.69
16	512,365.20	0.19	97,349.39
17	512,365.20	0.17	87,102.08
18	512,365.20	0.15	76,854.78
19	512,365.20	0.14	71,731.28
20	512,365.20	0.12	61,483.82
Net Present Value (NPV)			1,019,438.52

5.2.3.3. Evaluation of Feasibility of Investment of Wood Biomass Boiler and Recommended Motors

There are four techniques to evaluation feasibility of investment. Those are:

- Payback Period,
- Net Present Value (NPV),
- Internal Rate of Return (IRR), &
- Profitability Index.

1. **Payback Period (PBP) Technique**

The payback period should be shorter. It is recommended that the payback period should be less than or equal to five years for the feasibility of the investment.

2. **Net Present Value (NPV) Technique**

The NPV should be greater than zero for feasibility of the investment.

3. **Internal Rate of Return (IRR) Technique**

IRR is the discount rate that would result in a net present value of zero. For the feasibility of an investment, IRR must be greater than the actual discount rate.

4. **Profitability Index (PI) Technique**

It is an investment appraisal technique calculated by dividing the present value of future cash flows of an investment by the initial investment required for the investment.

Therefore,

$$PI = \frac{Present\ \text{Value of Future Cash Flows}}{Initial\ \text{Investment Required}}$$

$$PI = 1 + \frac{NPV}{Initial\ \text{Investment Required}} \qquad (5.32)$$

Based on the above four criteria, we can now evaluate the investment as follows:

Table 5.58: Evaluation of Feasibility of Investment

Investments	PBP (years)	NPV (Birr)	IRR (%)	PI	Evaluation of Investment
Criteria	PBP ≤ 6	NPV > 0	IRR > r (r = 11)	PI > 1	Acceptable
Boiler	5.28	12,253,468.52	18.70	1.60	Acceptable
Motors	5.20	1,019,438.52	15.86	1.33	Acceptable

CHAPTER 6: RESULTS AND DISCUSSION

6.1.Electric Steam Boiler

Table 6.1: Evaluation of Tolerances of Measured Values of Mass Flow Rates for Electric Steam Boiler

Mass Flow Rates	Average Measured Values (kg/h)	Calculated Values (kg/h)	% Error	Evaluation of Tolerances
Average Input Power ≅ 8.68 MW				
Steam Produced	11,097.15	12,348.00	10.13 %	Accepted
Condensate Return	8,119.75	9,036.00	10.14 %	Accepted
Feed Water	11,967.91	13,140.00	8.92 %	Accepted
Makeup Water	3,829.03	4,104.00	6.70 %	Accepted

Table 6.2: Nameplate Powers and Steam Production Rates for Electric Steam Boilers

Electric Steam Boilers	Nameplate Powers (MW)	Steam Production Rates (kg/h)
Smaller Boiler	3.00	4,302
Larger Boiler	6.00	8,600

In electrical engineering, mechanical engineering and other discipline, the power rating of equipment (for example boilers) is defined as the highest power input allowed to flow through particular equipment.

From the above table, it is clearly known that the average input power is nearly 8.68 MW when using both of the two electric steam boilers and the measured steam production rate is 11,097.15 kg/h. The sum of the nameplate steam production rates of the two boilers is 12,902 kg/h. Therefore, the measured steam production rate is acceptable because it is lower than the nameplate value.

Based on the above explanation, the measured values of the mass flow rates of condensate return, feed water and makeup water are definitely accepted on condition that the mass flow rate of the steam production is accepted. From the above table, all percentage errors are almost found within ± 10 %. Thus, they are accepted.

6.2. Wood Biomass Boiler

6.2.1. Heating Values of Wood Biomass

Table 6.3: Percentage Errors of Measured Heating Values of the Selected Wood Biomass

Heating Values	Measured Values (MJ/kg)	Calculated Values (MJ/kg)	% Error	Evaluation of Tolerance
LHV	14.65	15.19	3.60 < 10.00	Accepted
HHV (Wet Weight Basis)	18.30	17.43	4.99 < 10.00	Accepted
HHV (Dry Weight Basis)		20.51		

Table 6.4: Evaluation of Tolerance of HHV (Dry Weight Basis) based on a Benchmark

Fuel	Benchmarked HHV (MJ/kg)	Average Benchmarked HHV (MJ/kg)	Calculated HHV (MJ/kg)	% Error	Evaluation of Tolerance
Eucalyptus (Dry Weight Basis)	19.0-19.6	19.30	20.51	6.27 < 10.00	Accepted

Source for Benchmark: Jenkins, B., Properties of Biomass, Appendix to Biomass Energy Fundamentals, EPRI Report TR-102107, January, 1993.

We note that these values are based on the United States of America and European literatures. Even if we tried to get the relevant literatures about the biomass properties of Eucalyptus in Ethiopia, it is difficult to get enough information about that. This can be considered as one of the limitations of this research.

From the above table, all percentage errors are almost found within ± 10 %. Thus, they are accepted.

6.2.2. Combustion Properties of the Selected Wood Biomass

Table 6.5: Evaluation of Combustion Properties of the Selected Wood Biomass

№	Properties	Calculated Values
1	Stoichiometric Air-Fuel Ratio	1.12
2	Actual Air-Fuel Ratio	1.32
3	Combustion Air Ratio	7.2484

Notation: The Designed Air-Fuel Ratio = 1.65.

Therefore, the Actual Air-Fuel Ratio is 80 % of the Designed Air-Fuel Ratio. That is safe!!

6.2.3. Properties of Flue Gas Composition

Table 6.6: Evaluation of Flue Gas Components

№	Flue Gas Components	Calculated Values of Mass Percentage
1	Carbon Dioxide	22.455 %
2	Water	6.545 %
3	Sulphur Dioxide	0.0128 %
4	Nitrogen	70.988 %
Total		100.000 %

Table 6.7: Evaluation of Flue Gas Properties

№	Properties	Calculated Values
1	Flue Gas Ratio by Mass	7.8382
2	Absolute Humidity of Flue Gas	6.545 %
3	Density of Flue Gas @ Standard Conditions	1.210 kg/m^3
4	SO_2 Emission per Hour @ Standard Conditions	155 mg/m^3
5	Ratio of CO_2 Generation	0.433 kg/kWh

6.3.Recommended Electric Motors

Table 6.8: Efficiencies of the Three Selected Motors

Motor	Type	Efficiency
Hydra-Pulper Mill Drive Motor	Induction A.C. Motor	54 %
Hydra-Refiner Motor	Induction A.C. Motor	58 %
Dryer's Line-Shaft Motor	Continuous D.C. Motor	57 %

The above three electric motors were bought on 1966 on Gregorian calendar, from American companies, before 50 years based on the information obtained from EPPSC.

Most electric motors manufactured prior to 1975 were designed and constructed to meet minimum performance levels as a trade-off for a low purchase price. Efficiency was maintained only at levels high enough to meet the temperature rise restrictions of the particular motor. In 1977, the National Electrical Manufacturers Association (NEMA), found in America, recommended a procedure for labeling standard three-phase motors with an average nominal efficiency. These efficiencies represent an industry average for a large number of motors of the same design.

Source: Electrical Apparatus Service Association, Inc., St. Louis, Montana, USA.

Causes for Decreasing the Efficiency of Electric Motors:

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types:

1. Fixed Losses – Independent of motor load
2. Variable Losses – Dependent on motor load

1. Fixed Losses

They consist of magnetic core losses and friction and windage losses. Magnetic core losses (sometimes called iron losses) consist of eddy current and hysteresis losses in the stator. They vary with the core material and geometry and with input voltage. Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.

2. Variable Losses

They consist of resistance losses in the stator and in the rotor and miscellaneous stray losses. Resistance to current flow in the stator and rotor results in heat generation that is proportional to the resistance of the material and the square of the current (I^2R). Stray losses arise from a variety of sources and are difficult to either measure directly or to calculate, but are generally proportional to the square of the rotor current.

Causes for Failure of Electric Motors:

Normally eclectic motors do not fail suddenly. It happens over time and regular inspection will detect a problem before a serious situation develops. Faults in an A.C. Induction Motors (ACIMs) can occur in any of the three main components of the motor such as stator, rotor and bearings. Faults in the induction motor drives can be classified into three different groups:

1. Growing faults with only small effects on the operation.
2. Partial non-catastrophic faults with emergency operation possible.
3. Catastrophic faults with total drive breakdown.

a) **Mechanical Causes of Failure**:

- Misalignment
- Mechanical unbalance
- Soft foot
- Bearing fatigue
- Fractured rotor bars or end rings
- Overheating
- Loss of cooling
- Improper lubrication

b) **Electrical Causes of Failure**:

- Poor power quality
- Resistance and impedance unbalance
- Insulation failure
- Excessive loading and current

6.4.Total Net Annual Savings

Table 6.9: Total Net Annual Savings

Items	Net Annual Savings (Birr)	Net Annual Savings (USD)
Wood Biomass Boiler	3,894,255.57	179,541.52
Recommended Electric Motors	512,365.20	23,622.19
Total	4,406,620.77	203,163.71

From EPPSC, it is obtained that the annual profit is nearly 3.8 Million Birr (175,195.94 USD) for the annual turnover of 68 Million Birr (3,135,085.29 USD) and the annual production of 450,000 tons. Consequently, the annual profit will increase by 116 % on condition that the recommended investment is implemented in the company.

6.5.Evaluation of Feasibility of Investment

Table 6.10: Evaluation of Feasibility of Investment

Investments	PBP (years)	NPV (Birr)	IRR (%)	PI	Evaluation of Investment
Criteria	PBP ≤ 6	NPV > 0	IRR > r (r = 11)	PI > 1	Acceptable
Boiler	5.28	12,253,468.52	18.70	1.60	Acceptable
Motors	5.20	1,019,438.52	15.86	1.33	Acceptable

Therefore, this investment is definitely acceptable based on the above four criteria of the evaluation of feasibility of investment.

CHAPTER 7: CONCLUSION AND RECOMMENDATION

7.1.Conclusion

7.1.1. Environmental Consideration

The major pollutants in the flue gas composition analysis of this thesis are:

a) CO_2 (It is a Green House Gas)

b) SO_2

7.1.1.1. CO_2 Consideration

Table 7.1: Evaluation of Emission in Kg CO_2/KWh

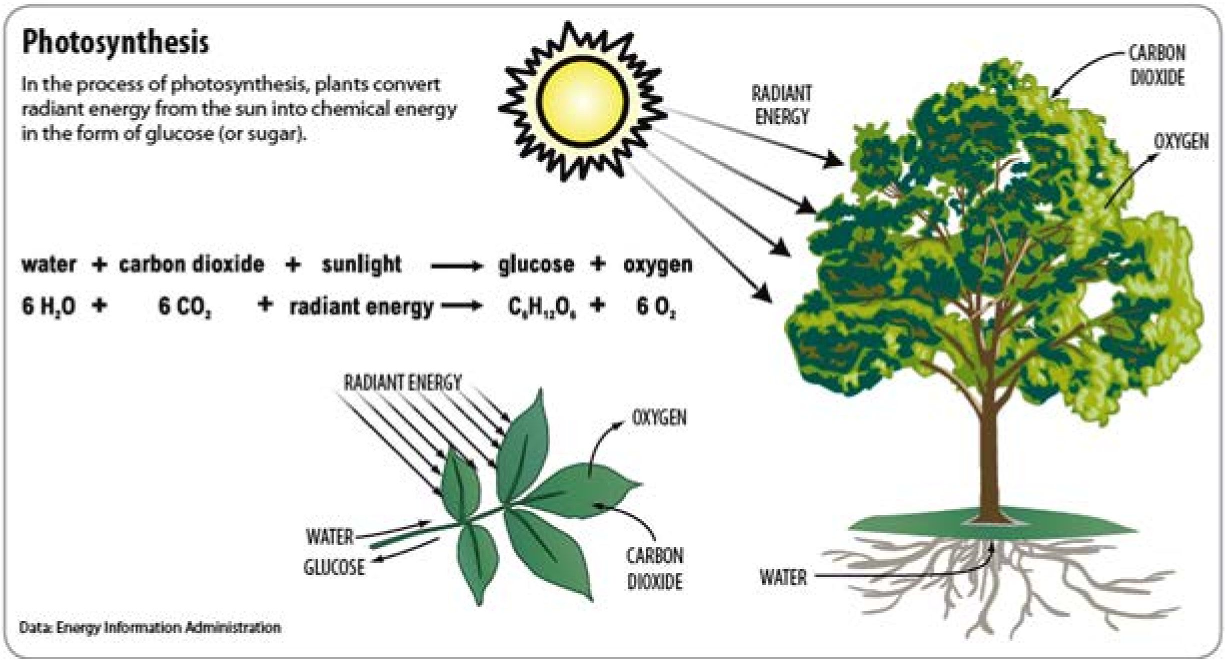
Fuel	Calculated Value of Emission in kg CO_2/kWh	Benchmarked Value of Emission in kg CO_2/kWh	% Error
Wood Logs	0.433	0.390	11.03 %

Source for Benchmark: Fachbuch Regenerative Energiesysteme and UBA

Based on the above table, the calculated value of emission in kg CO_2/kWh is almost acceptable because its percentage error is around 10 %. Thus, the emission in kg CO_2/kWh when using the selected wood biomass will never have any environmental influences like global warming.

Carbon dioxide is always a by-product of combustion. The level of carbon dioxide released is dependent upon the type of fuel used and the combustion process. Although naturally produced through respiration and other organic processes, carbon dioxide is a Green House Gas (GHG) and thus advances global warming if it is found excessively in the environment. GHG is a gas that stays in the air for a long time and warm-up the planet by allowing sunlight to pass but trapping infrared from the earth back to space. This is called the “green house effect” because the gas acts like the glass in a green house.

It is also known that CO_2 is one of the raw materials for photosynthesis. Without sufficient amount of CO_2 in the environment, photosynthesis can never occur. Therefore, the amount of CO_2 found in the environment determines its characteristics either to advances global warming or to use for photosynthesis.



Source: www.NEED.org

Figure 7.1: The Use of CO_2 for Photosynthesis

Therefore, wood biomass is a renewable and CO_2 neutral source of energy, which, if used in a sustainable and efficient way can contribute to a cleaner environment. Wood has been used as a source of fuel for millennia and is still used in households around the world.

7.1.1.2. SO_2 Consideration

Table 7.2: Emission Standard for Bio-energy Power Plant

Pollutant	Concentration (mg/m^3)
SO_2	≤ 200

Source: Ministry of the Environment on Installation Emission Standards, Directive of the EU Parliament and EU Council 2010/75/UE of 24 November, 2010.

We already calculated the SO_2 emission to the atmosphere per hour at standard conditions and we got 155 mg/m^3. Based on the above table, this calculated value is acceptable. Therefore, using wood biomass emits below the acceptable level of SO_2 to the atmosphere. That is because wood has practically no Sulfur (S) at all, as it's share in wood is 0.05 % at the highest (Pohjonen 1994).

The harmfulness of SO_2 is described as follows: It combines with water vapor in the exhaust to form a sulfuric acid mist. Airborne sulfuric acid is a pollutant in fog, smog, acid rain and snow, ending up in the soil and ground water. SO_2 itself is corrosive and harmful to the environment.
SO_2 occurs when the fuel contains sulfur and where the emission levels are directly related to the amount of sulfur in the fuel. The most cost-effective way to reduce sulfur emissions is to select a low-sulfur or de-sulfured fuel just like wood biomass.

7.1.2. Economic (Profit) Consideration

We have already known that the annual profit would be increased by 116 % on condition that the recommended investment will be implemented in the company. In addition, there is a finished proposal from EEPCo to increase the tariff of electric energy utilization by 50 % in the very near future. The above-mentioned facts show that the future annual profit will be much higher than the current calculated provided the recommended investment will be implemented in the company. Therefore, we can conclude that wood biomass boiler can perfectly be the economic choice for the electric steam boiler.

7.1.3. Conclusion Regarding the Three Selected Motors

Based on the detail calculation done from page № 66-73, the efficiencies of the three selected motors are below 60 % even if their power factors becomes 0.87 by using power factor corrector because of the very high losses caused by different factors due to their age (please read again page № 98-99). The current modern motors have efficiencies almost 96 % and using these motors instead of the selected three motors can provide the advantage of gaining the net annual savings of 512,365.20 Birr (23,622.19 USD). The payback period for investing the recommended new motors is only 5.20 years. All the above-mentioned facts can justify that the investment of those new motors is acceptable.

7.2. Recommendation

The following are recommended to be considered as future works to provide opportunities for the next logical steps of this thesis:

1. Waste Heat and Steam Recovery
2. Environmental Aspects during Paper Production
3. Forestation

7.2.1. Waste Heat and Steam Recovery

From the repeated experimental measurements taken in the drying unit, only 68.75 % of the steam can return back as a condensate return by using the electric steam boiler. Thus, 31.25 % of the steam is lost in the drying unit. That is a very high wasting of heat and steam in the drying unit. With today's high energy cost, we must return the highest percentage of condensate back to the boiler plant to be reused in the boiler by using economizer whatever the boiler type is.

The benchmark for the optimum condensate return percentage is up to 90 %. This benchmark is possible if the plant does not have requirements of direct steam injection for process applications.

Source: Swagelok Energy Advisors, Inc. Document № 20.

7.2.2. Environmental Aspects during Paper Production

The most significant environmental aspect of the mill of EPPSC during the operational phase relate to wastewater because there is no pulping process. There is only paper production process.

The environmental impact of paper is huge, resulting in high levels of consumption and waste, particularly in water environments. The pulp and paper industry is one of the largest and most polluting industries in the world, and is the third most polluting industry in Canada and the United States of America. Primary concerns when evaluating these disastrous effects are the use of chlorine-based bleaches causing toxic emissions to air, water and sediment. In waters near paper mills, habitats and their embodied ecosystems often conform to these unnatural effects created by the harsh chemical discharge. Besides the death of much marine life, the effects result in a negative evolution of particular species, thus creating a chain reaction to other organisms and environmental aspects. Previous studies have found that paper mill effluent causes reproductive impairment in zooplankton and in vertebrates, both of which are food for fish, and in shellfish and other fish species. Even if there is no a lake around the company, the afore-mentioned facts should be taken into consideration in order to protect the environment from any water pollution.

Dioxins, a major chemical included in the paper production process, represent a toxic compund produced by herbicide prodction and paper bleaching. When in contact, these can be a danger to humans, as well as animals when entering the lipids of their tissues. PCBs (Polychlorinated biphenyls), a toxic chlorinated chemical, increases as it moves through food chains associated with estuarine ecosystems. These chemicals often have harmful effects on the marine environments and the organisms residing in them. Past studies have demonstrated the damaging effects dioxins and PCBs have on aquatic ecosystems, and how they are carcinogenic to humans. Due to these chemicals being present in sediment and marine organisms, a link has been established to transfer dioxins and other harmful chemicals to humans through the food chain process. Therefore, the appropriate air, water and sediment treatments must be taken during the bleaching process of paper production in the company.

7.2.3. Forestation

Table 7.3: The Land-Cover Types of Ethiopia & Their Magnitude/Proportion (WBISPP, 2005)

Land Cover Type	Area in Hectare	%
Cultivated Land	21,298,529	18.600 %
High Forests	4,073,213	3.560 %
Plantations	501,522	0.400 %
Wood-lands	29,549,016	25.800 %
Shrub-lands	26,403,048	23.100 %
Grass-lands	14,620,707	12.800 %
Afro-alpine	245,326	0.210 %
Highland Bamboo	31,003	0.027 %
Lowland Bamboo	1,070,198	0.970 %
Swamp	810,213	0.700 %
Water	828,277	0.720 %
Bare Rock, Soil, etc	15,359,409	13.400 %

Source: WBISPP, 2005 (P.18)

From the above table, it is possible to understand that 25.8 % of the land-cover types of Ethiopia is wood-lands. From the wood-plants, eucalyptus takes the highest proportion. Arsi region, in Ethiopia, that is very near to Wenji is also well-known with its very wide eucalyptus plantation.

Figure 7.2: Eucalyptus Plantation in Arsi

In general, eucalyptus is the widely planted tree in Ethiopia. It was introduced to Ethiopia in either 1894 or 1895, either by Emperor Menelik II's French advisor Mondon-Vidailhet or by the Englishman Captain O'Brian. Menelik II endorsed its planting around his new capital city of Addis Ababa because of the massive deforestation around the city for firewood.

According to Richard R.K. Pankhurst, "The great advantage of the eucalypts was that they were fast growing, required little attention and when cut down grew up again from the roots; it could be harvested for bio-fuel in as little as 6 to 8 years. The tree proved successful from the onset".

Eucalyptus has very good prospects for the future. Worldwide demand for industrial forest products or using wood as a fuel has been rising and will continue to rise, and plantations provide an increasing proportion of these products.

Therefore, it is recommended that EPPSC should have its own plantation area for eucalyptus provided that it will use wood biomass boiler instead of electric steam boiler. Moreover, the plantation should occur based on at least the deforestation magnitude.

APPENDIX

1. The following MATLab code is used to plot Lower Heating Value over Moisture Content graph:

```
clear all
x = [0:0.05:0.60];
y = [0:1.5:20];
HHV = 18.30;
y = HHV*(1-x)-2.447*x;
plot(x, y, 'k');
xlabel('Moisture Content (Decimal Fraction)');
ylabel('Lower Heating Value (MJ/kg)');
title('Lower Heating Value over Moisture Content Graph');
grid on
```

2. The following MATLab code is used to plot the Continuous D.C. Motor Torque vs Rotational Speed graph:

```
clear all
x = [0, 1150, 1550];
y = [12.00, 3.097, 0.00];
plot(x, y, 'k');
xlabel('Rotational Speed (RPM)');
ylabel('Motor Torque (kN.m)');
title('Continuous D.C. Motor Torque vs Rotational Speed Graph');
grid on
```

3. The following MATLab code is used to plot the Continuous D.C. Output Power vs Rotational Speed curve:

```
clear all
x = [0:50:1550];
y = [0:50:490];
y = -0.000810732*x.^2+1.25664*x;
plot(x, y, 'k');
xlabel('Rotational Speed (RPM)');
ylabel('Motor Output Power (kW)');
title('Motor Output Power vs Rotational Speed Graph');
grid on
```

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