ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

# ENERGY AUDITING AND CONSERVATION IN TEXTILE FACTORIES

## (CASE STUDY: QUIHA MAA-GARMENT AND TEXTILE FACTORY

**By: Goitom Gebru**

**January, 2020 G.C**

**Addis Ababa, Ethiopia**

**ADDIS ABABA UNIVERSITY**

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**SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING**

# ENERGY AUDITING ANDCONSERVATION IN TEXTILE FACTORIES

**(Case study: Quiha Maa- Garment and Textile Factory)**

**A thesis submitted to Addis Ababa Institute of Technology Graduated Studies**

**in the partial fulfillment of the requirement for the degree of**

**Masters of Science in Electrical Power Engineering**

**By: Goitom Gebru**

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**January, 2020 G.C**

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**(Case study: QuihaMaa- Garment and Textile Factory)**

By: Goitom Gebru

Approved by Board Examiners

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# DECLARATION

Here I declare that this thesis with the title "Energy Auditing and Conservation in Textile Factories (case study Quiha Maa- Garment and Textile Factory)" is done by me for the first time that is it is not done in the last time in Addis Ababa University and other universities. The sources or equipment's I have used in this thesis are getting from the factory and from internet and they are acknowledge by the factory workers.

Name: GoitomGebru

Signature: ________________

Place: Addis Ababa

Date of submission__________________

This thesis is submitted for examination with my approval and my advisor.

**Dr. Getachew Bekele** ______________________

Advisor Name signature

# ACKNOWLEDGMENT

First of all thanks and praise to my GOD who give me health and strength to do my thesis.

I would like to say thanks also to my thesis advisor Dr. Getachew Bekele in giving his response in short period of time when I ask what I want from him and to his comments on my MSc thesis.

Further, I like to say thanks to Engineer Lenin the head of electrical department in the factory, Engineer Ashenafi, H/Mariam, Ethiopian Energy Minister energy audit team workers and to all of Quiha Maa Garment and Textile Factory workers to their interest to give the needed data to my thesis work.

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# ABSTRACT

Sufficient and reliable supply of energy is needed to develop any country in the world. But there is a problem in conversion and usage of these energy sources that is they causes high energy wastage, high cost of energy to convert and use and high carbon emission to the environment. This is most of the time occur in developing countries like Ethiopia which has low knowledge on energy conservations and usage, this make to these developing counties to generate higher energy instead of using the existing energy effectively [1]. Industries like textile, sugar and cement factories consume a large amount of energy but do not use effectively which results in paying of extra money that affects to the factory and to the country in general.

In this study we have used, software like Micro soft Visio and Microsoft excel to design diagrams and Motor Master Software which is used to select/choose the best and efficient motors based on their efficiency, cost effectiveness and energy savings. We have also used measuring devices such as portable flue gas analyzer, energy meter, thermograph, temperature probe, different reading gauges to get appropriate data of the equipment's.

Therefore, this thesis focuses on energy auditing and conservation in Quiha Maa-Garment and Textile Factory and its goal is to improve the energy efficiency of the industry by proposing energy efficiency increasing techniques. These techniques include replacing high energy consuming materials like changing of T12 lighting tubes by T8 lighting tubes, boiler air ratio control, implementing boiler flue gas waste heat recovery system, thermo boiler air ratio control, implementing thermo boiler waste heat recovery system, heat transport facility reinsulating, dyeing machine waste water heat recovery system, dyeing machine adiabatic paint coating, air compressor intake temperature improvement, using of energy efficient electric motors, changing damaged materials and by best rewinding of motors.

It is found that by adopting the suggested energy conservation techniques, the total electrical energy saving is 90.3Mwh/yr and the thermal energy saving is 129.304 kl/yr. Thus, the total energy saving converted into the same unit (i.e., toe/yr) is 137.13toe/yr. Further, it is observed that carbon emission reduction due to electrical energy saving is 11.151 tc/yr and the reduction on account of thermal energy saving is 98.525tc/yr. Thus, the total carbon emission reduces to 109.676tc/yr. Furthermore, it is found that the saving in cost on account of electrical energy is 52,061.5 birr/yr (or $ 1735.4), due to saving in thermal energy is 2,197,699.15birr/yr($73256.64) and total cost is 2249760birr/yr

Key Words**:** Maa-Garment and Textile Factory, energy efficiency improvement techniques, Microsoft Visio, portable flue gas analyzer, thermograph, Motor Master + international software.

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# List of Abbreviations

| | |
|---|---|
| BFWHR | boiler flue gas waste heat recovery |
| EM | electric motor |
| AC | air compressor |
| BARC | boiler air ratio control |
| TBARC | thermo boiler air ratio control |
| TBFWHR | thermo boiler flue gas waste heat recovery |
| DWWHR | dyeing waste water heat recovery |
| DAPC | dyeing adiabatic paint coating |
| HTFI | heat transport facility insulation |
| BN1 | boiler number one |
| BN2 | boiler number two |
| Hp | horse power |
| KSB | Korean standard of boiler |
| T/h | tonne per hour |
| Is | Indian standard |
| BS | British standard |
| Tc | tonne of carbon |
| H/E | heat exchanger |
| Kl | kilo liter |
| HPHT | high pressure high temperature |

# CHAPTER ONE

# INTRODUCTION

## 1.1. Back Ground of the Study

Energy is the ability to do work. Energy is the most important factor for development of any country due to many reason such as for making foods, to operate industries, for small business centers (hotels, super markets shops) generally it is a basic factor for fast development of any country. Today the need of energy is rapidly increasing in all sides of the world that is in poor, developing and developed countries to modernize their country. In developed countries the energy consumption by factories is high which covers 30-40% from the total energy needed by the country [1]. Even if the amount of energy generated in the world is better than the previous times but there is now also a shortage of energy especially in poor and developing countries, due to this reason human beings use fossil fuel supplies (including oil, coal and natural gas) to do their day to day activities, but using of those fossil fuels results in energy wastage during the process of converting the primary energy sources in to useful and global warming. Therefore, effective use of energy is good to solve the entire problem listed above especially global warming.

The energy efficiency of many factories is below the standard value; this shows that there are many techniques for increasing the energy efficiency of the factories. Energy efficiency is the ratio of the productive output of a device to the energy it consumes and improving energy efficiency means identifying wasteful energy use and taking actions to reduce or illuminate that waste. Increasing energy efficiency results, in decreasing cost of energy, decreasing energy waste, reduce greenhouse gases emissions and consequently increase the factories profitability. Increasing energy efficiency is an essential step to reach the plan of energy policy these are security of supply, keeping of the environment clean and decreasing cost of energy use. Planning on how energy is run by putting an organization is one of the best and cost-effective methods to select the best energy efficiently improving techniques. Energy management is a system of computer aided tools used by operators of electric utility grids to monitor, control and optimize the performance of the generation transmission system it can also use in small scale systems like micro grids [2]. Deep study on energy usage, efficiency increasing techniques, energy controlling methods and putting of cost effective technologies is important due to many reasons that is it helps to save energy wastage and results in protecting the environmental from pollution.

In more developed countries30- 40% of the total energy is consumed by factories [3]. These factories consume both the electric power and oil by different materials such as by motors, thermo boiler, boilers, air compressors, furnaces, and etc. few factories in the world now are decreasing their energy consumption by putting and improving energy efficient machines and by using different energy management techniques. These are the best methods for high energy waste minimization and environmental pollution caused due to energy loss [4].

Most of the times factories are focused to some curtail cases, like market conditions but they don't give attention on waste energy minimization.

There are many high energy consuming factories in Ethiopia which distress to extraordinary energy consumption and costs. These factories include like cement factory, sugar factory, textile factory and etc. Factories must work to enable their efficiency higher in their usage of electric energy based on Ethiopia standard ad these factories must be controlled and checked by Ethiopian Electric Energy minister. But in Ethiopia controlling of factories their operating efficiency not used yet due to this factories are suffered to many problems such as, they ordered to pay a lot of money on energy bills, causes environmental problems and the factories are not competitive.

It is better to implement new energy improvement techniques for many purposes such as to increase the energy efficiency of the factories, to decrease cost of energy, to decrease energy consumption and to decrease carbon emissions to the environment.

In Ethiopia textile factory is one of among the higher energy consuming factories which have a great role in the development of the country. In Ethiopia there are 73 textile factories, these textile factories consume a large amount of energy. From these factories Quiha Maa-Garment and Textile Factory is one which is located in the northern part of Ethiopia which has a large energy waste due to use of inefficient machines, poor winding of motors, loss in insulation, absence of reuse techniques and etc. Therefore to solve the energy wastage due to inefficient use of equipment's energy auditing and conservation technique is the best method which saves energy by identifying the areas (equipment's) which causes energy waste by proposing energy improving techniques.

## Energy Audit

An energy audit is an examination, assessment and investigation of energy flows for energy conservation in a building, process or system to decrease the amount of energy input into the system without negatively affecting the output(s). It is a necessary commercial tool to save energy and to upgrade financial state of an organization. Energy audit help industrial factories or facilities in comprehension how they use energy and help to recognize the areas where waste occurs and where opportunities for improvement exists.

A quintessential industrial energy audit control depends on its operation, capacity, type of the factory, the deepness to which the audit is required and the capability and immensity of energy savings and cost decreasing desire. Energy audits steps are divided in to three those are [5]:

- **Walk-Through**:- is a least costly and it identifies preliminary energy savings.
- **Mini-Audit:-** needs tests and computations to assess energy uses and losses and regulate the economics for changes.
- **Maxi-Audit**: - goes one step further than the mini-audit, it evaluates how much energy is used for each function and it requires a model analysis (computer simulation) to determine energy use patterns and prediction on a year-round basis taking into account.

## Energy Conservation

Energy conservation is the attempt made to decrease the use of energy by using less energy consuming equipment's. Energy conservation is a constituent of the abstraction of eco-sufficiency. Eco-sufficiency needs decreasing in the use of energy, natural resources and in the generation of waste (among which greenhouse gas emissions) in complete terms.

Energy conservation decreases the energy requirement by different equipment's and can result in increased environmental quality, national security, personal financial security and higher savings [6]. It is at the top of the sustainable energy hierarchy and it also decreases energy costs by controlling future resource depression. Energy can be preserve by decreasing wastage and losses, improving efficiency through technological ameliorate and upgrading operation and maintenance. On a global level energy use can also be reduced stabilization of population growth.

## 1.2. Statement of the Problem

In Ethiopia there is inefficient use of energy which results in shortage of supply. Due to this shortage of energy about 70% of our people don't get electricity and they use fossil fuel supplies to do their activities and factories don't operate in full time. When the peoples especially living in remote areas use fossil fuels supplies to do their activity they causes wastage of energy during the process of converting these fuels to useful energy and results in global warming.

In Ethiopia most of the factories loss large amount of electrical and thermal energy because these factories use inefficient materials, they don't give attention to energy loss due to these inefficient materials and don't take energy audit therefore, and they don't know how much energy is loss. This loss of loss of electrical and thermal energy results to environmental pollution high cost of energy and the factories production is less.

This thesis focuses on the electrical and thermal energy losses in Quiha Maa Garment and Textile Factory, their causes, consequences and techniques of improving energy efficiency of the materials.

## 1.3. Objectives of the Study

**General Objective**

The general objective of this thesis is to study the areas which cause energy waste in Quiha Maa Garment and Textile Factory and to propose improving opportunities used to minimize energy wastage.

**Specific Objectives**

The specific objectives of the thesis are as listed below:

- Plainly/distinctly point out the energy use and its cost by the Quiha Maa Garment and Textile Factory.
- Comprehension on energy use and reasons for loss in Quiha Maa Garment and Textile Factory.
- Point out the techniques of upgrading energy conservation and cost minimization techniques.

- To draw conclusion based on the above investigations and to recommend possible energy saving opportunities of energy saving in boiler, thermo boiler, dyeing, air compressor and use of lamps.

## 1.4. Scope and Significance of the Study

**Scope of the Study**

This thesis focuses on Energy audit and conservation in Quiha Maa- Garment and Textile Factory to improve the product of the factory, to minimize energy wastage, to reduce belling cost and to identify the equipment's which causes energy waste or loss due to use of less efficient equipment's, improper rewinding of equipment's, poor maintenance of equipment's and old equipment's.

Facilities concentrated on this audit are Boiler, Thermo-boiler, Dyeing machine, Air Compressor, Heat transport facilities and Light lamps.

**Significance of the Study**

Through energy audit, we can:

- upgrade our knowledge on the use of non-renewable energy resources
- know the cost of energy use and energy use rate
- increase knowhow on energy use patterns
- study and propose energy waste minimization techniques
- Make changes on the procedure, equipment's and systems to save energy
- Minimize environmental pollution by reducing power generation

## 1.5. Methodology

The methods we have used to study energy auditing and conservation in the factory are:

**Site visit**

From many currently existing textile factories in Ethiopia, the factory we selected for this thesis work is Quiha Maa-Garment and Textile Factory which is good for me to collect data because it is near to my work area and my friends are there and they can help me by giving information about the factory background and its operating condition.

**Data Collection**

The relevant data's we used in this thesis are collected from different sources. These data's are:

- The overall currently energy used by the factory(fuel and power)
- The result of readings and measurements of the equipment's which are operating under different cases to compare their efficiencies.
- The electrical and fuel energy consumption of each department (Spinning, Dyeing, Knitting and Garment).
- Requirements, operating conditions and preservation plans of the materials in the factory.
- The overall present production cost of the factory.
- Making opening conference, interview with managers, walk through tour with technicians by creating schedule to communicate with the factory manager.
- The operating condition of the currently existing electrical motors.
- Energy consumption of the existing equipment's such as Boiler, Thermo Boiler, air compressors, dyeing machines etc.

**Data Analysis and Modeling**

To show the result, we have used software's, mathematical models and measuring instruments. The software's we have used are Microsoft Visio, Microsoft excels and motor master software and the measuring devices we have used are:

- Energy meter → energy consumption
- Thermo graph →thermal image( shows radiation, temperature and area of insulation)
- Flue Gas analyzer---for % oxygen, carbon dioxide, CO, temperature of flue gas etc.
- Reading gauges→ fluid temperature, volume flow rate of steam ($m^3/s$), steam pressure (bar) and steam temperature.
- Combustion analyzer→ combustion amount of oxygen, fuel and etc.

In this thesis we done data analysis according to the relevant data we collected from the factory and this analysis help to know the operating condition of Quiha Maa- Garment and Textile Factory. These collected data helps to select the areas which show large energy loss and to propose energy saving techniques which minimize energy waste and cost of energy.

## 1.6. Motivations of the study

The motivations we initiated to do a thesis on energy audit in Quiha Maa Garment and Textile Factory are as listed below:

- Increasing in energy costs
- Environmental problems (increase in global warming) due to increase in greenhouse gas emission and resource depletion
- Less profitability of the factory (the factory is not competitive)
- Due to decreasing or scarce in supply of resources( eg. fuel)

## 1.7. Outline of the Thesis

This thesis includes five chapters. The first chapter focuses on introduction of energy audit and conservation and the second chapter focuses on the manufacturing process of Quiha Maa Garment and Textile Factory. The third chapter deals with the data collection methodologies and discusses major energy uses both the electrical and thermal energy in each departments and main equipment's. The fourth chapter discusses about the opportunities/ techniques used for energy saving in different equipment's with a deep calculation to suggest whether the used opportunities are effective in terms of saving in cost, energy and in reduction in greenhouse gas emission. And the fifth chapter deals with analytical result analysis, conclusions, recommendations and future work.

## 1.8. Literature review

In order to address the problems focused in this thesis, we need to have a literature review and a broad knowledge of the issues regarding energy auditing, conservation and efficiency improvement opportunities in industries and the methods for resolving these issues as presented below.

**T. Ashokkumar, P. Raja and Rahmath Ulla Baig**[11] this researcher paper deals with energy conservation and efficiency of both electrical and thermal energy. In their study, they suggested three techniques of energy conservation and efficiency improving methods these techniques are, efficiently use of electrical materials, replacing of the existing inefficient materials without investment cost, and replacing of the existing materials with more efficient materials with less cost. But they did not show the benefits of the new energy efficient materials over the existing inefficient materials in terms of cost saving, energy saving, carbon emission reduction and their payback period.

**Eng. Basel Tahseen et.al** [12] this research paper deals with energy audit and energy conservation in different textile factories such as in Palestine and this research point out the most energy consuming areas of the factory. And it proposed techniques which can save energy waste by applying energy conservation techniques on the most energy consuming materials such as boiler, thermo boiler, air compressors and lamps and dyeing machines at the last he conclude by using efficient materials 10- 20% of total energy used by the materials can be saved. But this research did not show energy savings, cost savings and carbon reduction in mathematical form.

**Oyedepo, et al** [13] this research describes the energy consumption in food factories, air-conditions and bottling factory and it studies the causes of electrical energy wastes in boilers, thermo boilers, pumps, air compressor, and electric motors. Evaluating the energy usage in these equipment's shows 65% from the total electrical energy is used by boiler and thermo boiler and 40-47% from the total electric energy is used by pumps, air compressor and electric motors. Then by changing the existing less efficient electric motors with efficient motors and by replacing the existing ventilation with good ventilation we can save a large amount of energy. But this research does not show the amount of energy savings, cost savings, carbon emission reduction and payback period mathematically.

**Aftab Khan Masood** [14] this research paper deals on the studies of 40 energy efficient technologies and methods of improving energy efficiency of different equipment's which results in energy savings, carbon emission reduction, investment cost reduction, and operation and maintenance costs reduction. The research paper shows the techniques and experiences on how to improve the energy efficiency of textile factory. But it does not include all the equipment's in the factory and does not calculate their payback period whether it is cost wise or not.

**Jatin Gupta** [15] this research deals with study of Electrical Energy Audit of induction Motors in Textile factory. The main aim of studying on textile factory is to identify the possible energy saving techniques such as in induction motors, dyeing machines, air compressors and lightings which show high energy loss. After he made study on the replacement of electric motors with energy efficient motors, he conclude that replacing of the existing inefficient motors by new efficient motors is cost wise and he get a payback period of 2.6 year.

Generally literature review helps to identify the causes of energy waste and the techniques or opportunities used to minimize the energy wastage. But these literatures don't show in mathematical form how much energy is wasted due to inefficient equipment's and how much energy is saved due to the new replaced efficient equipment's by calculating the greenhouse gas emission reduction, cost reduction, energy saving and payback period to know whether the new replaced equipment is cost effective or not . Now we have study all the problems listed in statement of the problem, their improvements and we have shown whether the improving techniques better than the existing one or not by calculating energy saving, greenhouse gas emission reduction, cost saving and payback period of each improvements.

# CHAPTER TWO

# QUIHA MAA-GARMENT AND TEXTILE FACTORY MANUFACTURING PROCESS

## 2.1. Overview of Quiha Maa Garment and Textile Factory

Quiha Maa-Garment and Textile Factory is a privately owned factory started and registered in April 2001 G.C under the commercial laws of the federal democratic republic of Ethiopia. Quiha Maa-Garment and Textile Factory is located in the north part of Ethiopia 783 kilometer far from Addis Ababa and 12 kilometer far from Mekelle in Quiha sub city near to Alula Abanega international airport.

Figure 2-1: Over view of Quiha Maa- Garment and Textile Factory

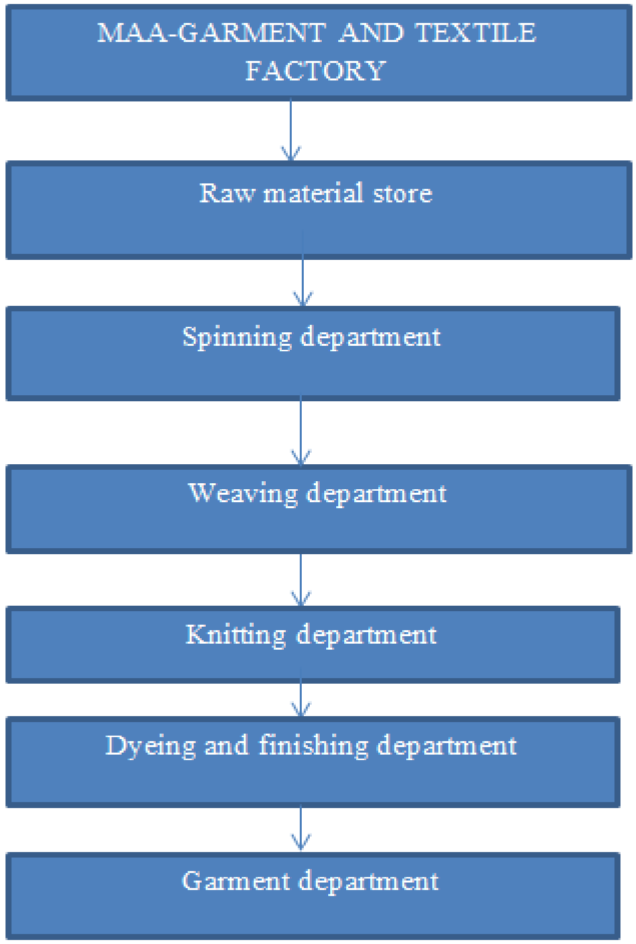


Figure 2-2: Over all work flow of the factory

## 2.2. **Main products, customer and suppliers of the company**

**Main products**

The main products of the factory are:

- T-shirt, Polo shirt and fitted bed sheet with 100% cotton, co/lycra.
- Definitive shirts of cotton and cotton/polyester materials.
- Summer shorts of 100% cotton or other fabrics.
- Panties for all age groups and for both sexes.
- Ladies blouses of different styles.
- Children's cloth of a different of materials.
- Best standard work garments both of cotton and cotton/polyester fabrics.


Figure 2-3: Main products of Quiha Maa Garment and Textile Factory

**Main customer of the company**

The main customer or end users of the product of Quiha Maa-Garment and Textile Factory can be categorized in to two groups:

a. **Local customer**

The local users of the factory are:-

- Small business enterprises.
- Potential customer(e.g. Regional police of Tigray)
- nongovernmental potential customers(e.g. Guna trading, schools, hospitals)

b. **Foreign customers**

Table 2-1: Foreign customers of Quiha Maa Garment and Textile Factory

| No | Customer | Countries |
|---|---|---|
| 1 | EDWARDS | USA |
| 2 | WALLS/WALL | WALES |
| 3 | OBERMEYER | GERMANY |
| 4 | HANS | GERMANY |
| 5 | MOC | USA |
| 6 | DVH | USA |
| 7 | BONGHWA | USA |
| 8 | KIK | GERMANY |

**Suppliers of raw material and accessories of the company**

The main raw materials of the company are cotton and polyester. But now about 98% is processed cotton fiber, based on the requisition from customers.

Table 2-2: Supplier of raw material and accessories

| Type of raw material and accessories | Suppliers |
|---|---|
| Cotton fiber | Middle awash and Humera |
| polyester | Turkey and Coria |
| Dye staffs | Turkey and Germany |
| Machine spare part | Japan and Germany |
| Fabric accessories | China |

## 2.3. Organizational Structure of Quiha Maa Garment and Textile Factory

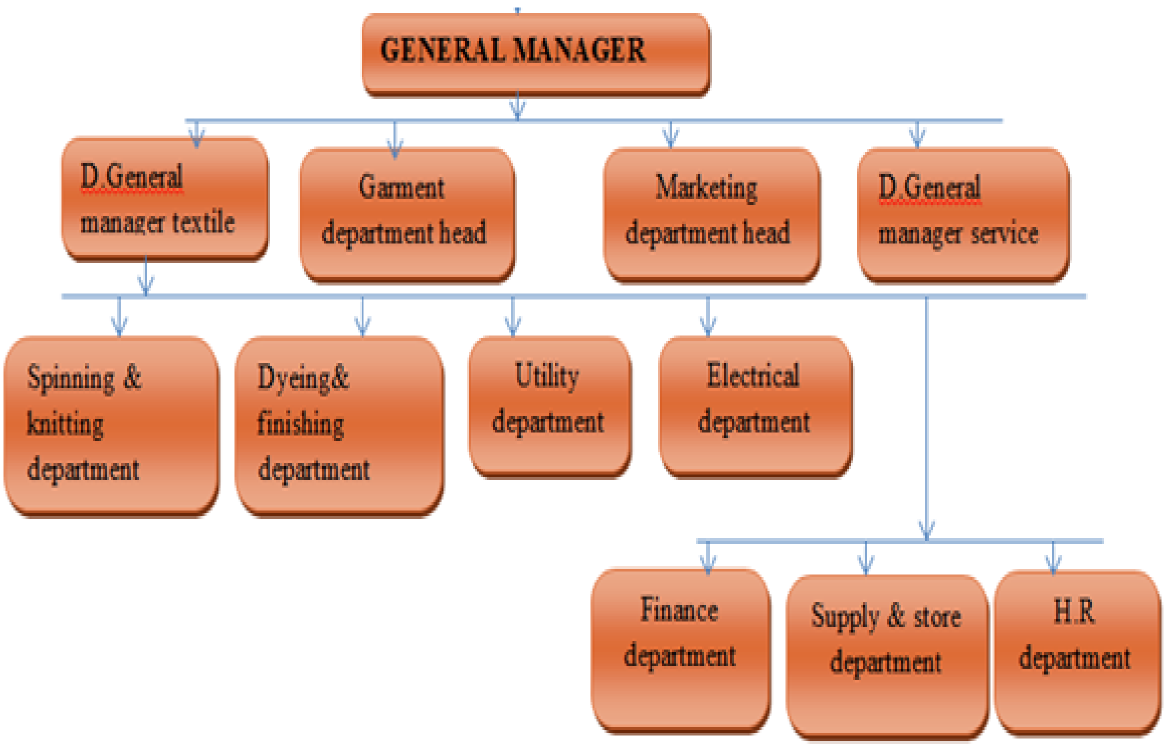


Figure 2-4: Organizational structure of Quiha Maa Garment and Textile Factory

## 2.4. Departments in Quiha Maa Garment and Textile Factory

**Spinning Department**

In spinning department the raw materials (cotton and polyester) are converted to useable form of yarn. It is designed to produce 10 tons per day of yarn with the following composition:-

- 3 tons of rotors revolve yarn with mean count of Ne 20. But this machine can produce from Ne 10- Ne 30. Where Ne means metric count =1000m or 1km height
- 3 tons of ring revolve groom yarn of mean count of Ne-30
- 4 tons per day of ring revolve card yarn of mean count of Ne-25.4
- The round frame machines can give from Ne-20 up to Ne-40.


Figure 2-5: Spinning department

**Knitting Department**

This department converts the yarn produced in spinning to smooth fabric that used to produce t-shirts. Its daily capacity is 6 tons. The plant comprises of 12 circular machines from mayer and cie (Germany) and four flat knitting machines from shima seki(Japan).

- 7 circular machines which produce single jersey and their derivatives with 20,24,and 28 gauges

- 3 machines which produce Rib with gauges of 15 and 18
- 2 machines which provide interlink with the size of 24


Figure 2-6: Knitting department

**Dyeing and Finishing Department: -** this department changes the color of the fabric produced in knitting. This plant comprises the latest laboratory and HPHT dyeing Machines and color kitchen. The HPHT machineries can dye knitted, woven made of 100% cotton and blends. The laboratory contains spectrophotometer, automatic dispenser (data color), sample dyeing machine, light fastness tester, Crock meter, per pyrometer, shrinkage tester, washing fastness machine, dryer and light cabinet materials. Dyeing section has a size up to 8.1 tons per day. It contains the following machineries:

- 1xmini soft machine with a size of 20 kg from thies(Germany)
- 1xeco master with a size of 180kg from thies(Germany)
- 2xeco master with a size of 540kg from thies(Germany)
- 1xeco master with a size of 900kg from thies(Germany)

Figure 2-7: Dyeing department

**Garment Department**

In this department the colorful clothes comes from processing and knitting department and convert to various types of cloths and other out puts.

Figure 2-8: Garment department

**Weaving Department:-**in this department the yarn out putted from spinning is used as in put to this department and converted to fabric form.

Figure 2-9: Weaving department

# CHAPTER THREE

# DATA COLLECTION

## 3.1. Energy use status and energy use rate of Quiha Maa Garment and Textile Factory

Table 3-1: Energy use status of Quiha Maa Garment and Textile factory

| Section | Unit | Energy use in 2018 year | Energy use rate |
|---|---|---|---|
| Fuel energy | kl | 893.13 | 23% |
| | toe | 804.71 | |
| Electric energy | Mwh | 11,605.26 | 77% |
| | toe | 2,669.21 | |
| Total energy | toe | 3,473.92 | 100% |

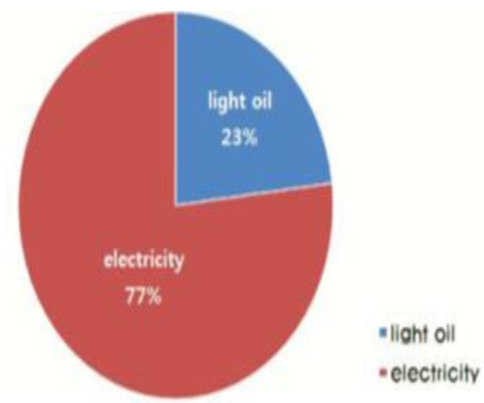


Figure 3-10: Energy use rate of Quiha Maa Garment and Textile Factory in 2018G.C

Where 1Kl = 0.901toe and 1MWh = 0.23toe where toe = tonnes of oil equivalent

$$\text{Energy use rate of E.power} = \frac{\text{energy use of electric power(toe)}}{\text{total energy use(fuel + power)(toe)}} * 100\% \qquad (3.1)$$

$$= \frac{2669.21(\text{toe})}{3473.92(\text{toe})} * 100\% = 77\%$$

$$\text{Energy use rate of fuel} = \frac{\text{energy use of fuel(toe)}}{\text{total energy use(fuel + power)(toe)}} * 100\% \qquad (3.2)$$

$$= \frac{804.71(\text{toe})}{3473.92(\text{toe})} * 100\% = 23\%$$

**Annual Light Oil Consumption of Quiha Maa Garment and Textile Factory in year 2018Gc**

Table 3-2: Annual fuel consumption of Quiha Maa Garment and Textile Factory

| month | light oil(ℓ) | Cost (birr) | Cost ($) |
|---|---|---|---|
| Jan. | 68,550 | 1,165,350 | 41,619.64 |
| Feb. | 66,292 | 1,126,964 | 40,248.71 |
| Mar. | 82,464 | 1,401,888 | 50,067.43 |
| Apr. | 74,396 | 1,264,732 | 45,169 |
| May | 67,692 | 1,150,764 | 41,098.71 |
| Jun. | 67,203 | 1,142,451 | 40,801.82 |
| Jul. | 82,384 | 1,400,528 | 50,018.86 |
| Aug. | 95,253 | 1,619,301 | 57,832.12 |
| Sep. | 72,388 | 1,230,596 | 43,949.86 |
| Oct. | 74,882 | 1,272,994 | 45,464.10 |
| Nov. | 77,491 | 1,317,347 | 47,048.11 |
| Dec. | 64,135 | 1,090,295 | 38,939.11 |
| Total | 893,130.0 | 15,183,210 | 542,257.5 |


Figure 3-11: Light oil consumption in 2018G.C

**Electrical Energy Consumption of each Department or section**

**a. Electric Energy Consumption in Garment Department**

Table 3-3: Electric power consumption in Garment department

| Month | Receiving power(kwh) | Total electric cost (birr) | Cost($) |
|---|---|---|---|
| Jan | 39,000 | 22,534.2 | 804.8 |
| Feb | 31,500 | 18,201 | 650 |
| Mar | 45,000 | 26,001 | 928.6 |
| Apr | 27,000 | 15,601 | 557.2 |
| May | 33,000 | 19,067 | 680.96 |
| Jun | 30,000 | 17,334 | 619.1 |
| Jul | 31,500 | 18,200.7 | 650 |
| Aug | 30,000 | 17,334 | 619.1 |
| Sep | 25,500 | 14,734 | 526.2 |
| Oct | 28,500 | 16,467 | 588.1 |
| Nov | 30,000 | 17,334 | 619.1 |
| Dec | 30,000 | 17,334 | 619.1 |
| total | 381,000 | 220,142 | 7862.2 |

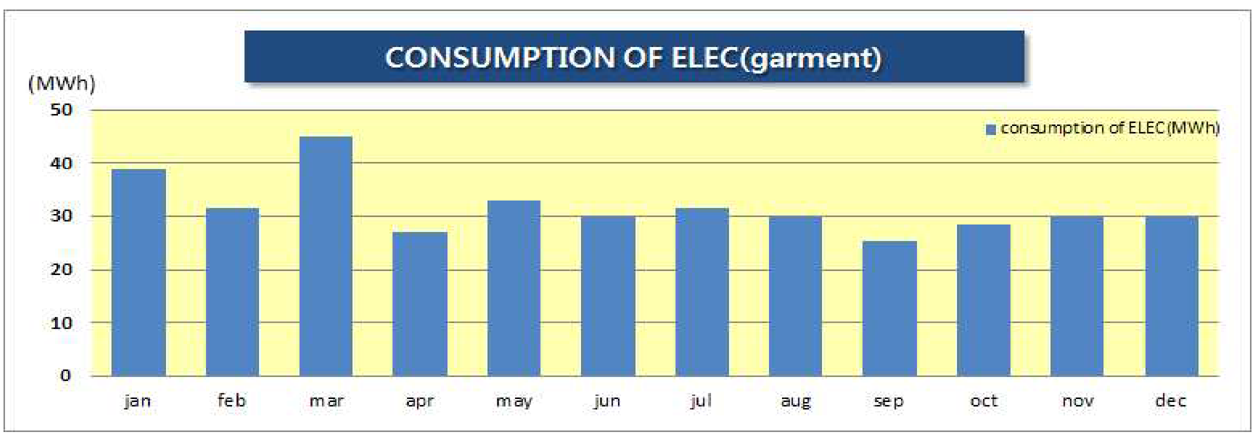


Figure 3-12: Electric power consumption by garment department

**b. Electric Energy Consumption by Dyeing and Finishing Department**

Table 3-4: Electric power consumption by Dyeing and Finishing department

| Month | Receiving power(kwh) | Total electric cost (birr) | Cost($) |
|---|---|---|---|
| Jan | 150,000 | 86,670 | 3095.4 |
| Feb | 115,500 | 66,736 | 2383.4 |
| Mar | 169,500 | 97,937 | 3497.75 |
| Apr | 94,500 | 54,602 | 1950.1 |
| May | 123,000 | 71,069 | 2538.2 |
| Jun | 106,500 | 61,536 | 2197.7 |
| Jul | 106,500 | 61,536 | 2197.7 |
| Aug | 97,500 | 56,336 | 2012 |
| Sep | 94,500 | 54,602 | 1950.1 |
| Oct | 109,500 | 63,269 | 2259.6 |
| Nov | 126,000 | 72,803 | 2600.1 |
| Dec | 121,500 | 70,203 | 2507.25 |
| total | 1,414,500 | 817,298 | 29189.21 |

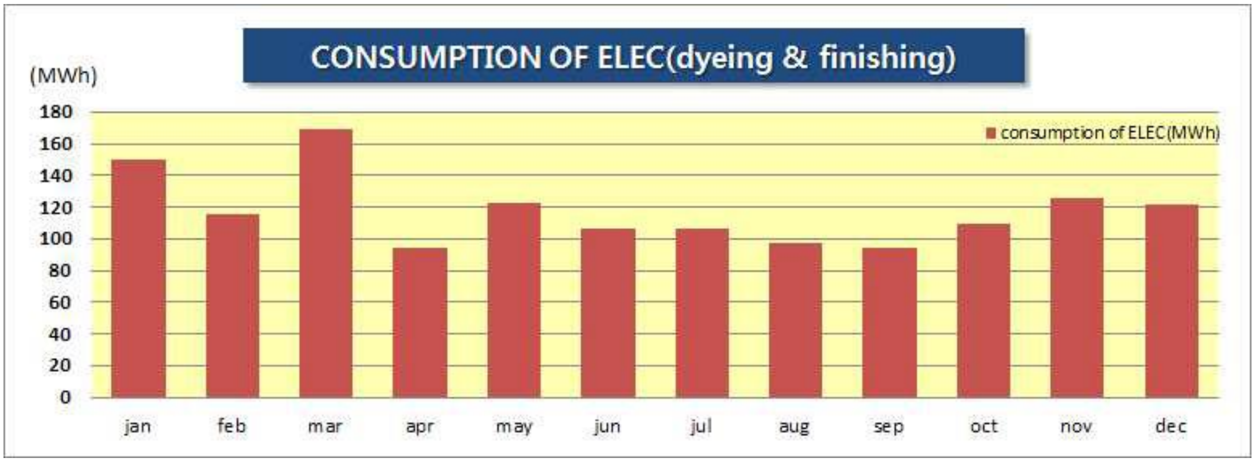


Figure 3-13: Electric power consumption by dyeing and finishing department

## C. Electric Energy Consumption in Spinning Department

Table 3-5: Electric power consumption in spinning department

| Month | Receiving power(kwh) | Total electric cost (birr) | Cost($) |
|---|---|---|---|
| Jan | 960,000 | 554,688 | 19819.3 |
| Feb | 756,000 | 436,817 | 15600.61 |
| Mar | 918,000 | 530,420 | 18943.57 |
| Apr | 276,000 | 159,473 | 5695.46 |
| May | 744,000 | 429,883 | 15352.96 |
| Jun | 846,000 | 488,819 | 17457.82 |
| Jul | 780,000 | 450,684 | 16095.85 |
| Aug | 876,000 | 506,153 | 18076.89 |
| Sep | 792,000 | 457,618 | 16343.5 |
| Oct | 882,000 | 509,620 | 18200.7 |
| Nov | 816,000 | 471,485 | 16838.75 |
| Dec | 714,000 | 412,549 | 14733.89 |
| total | 9,360,000 | 5,408,208 | 193,150.28 |

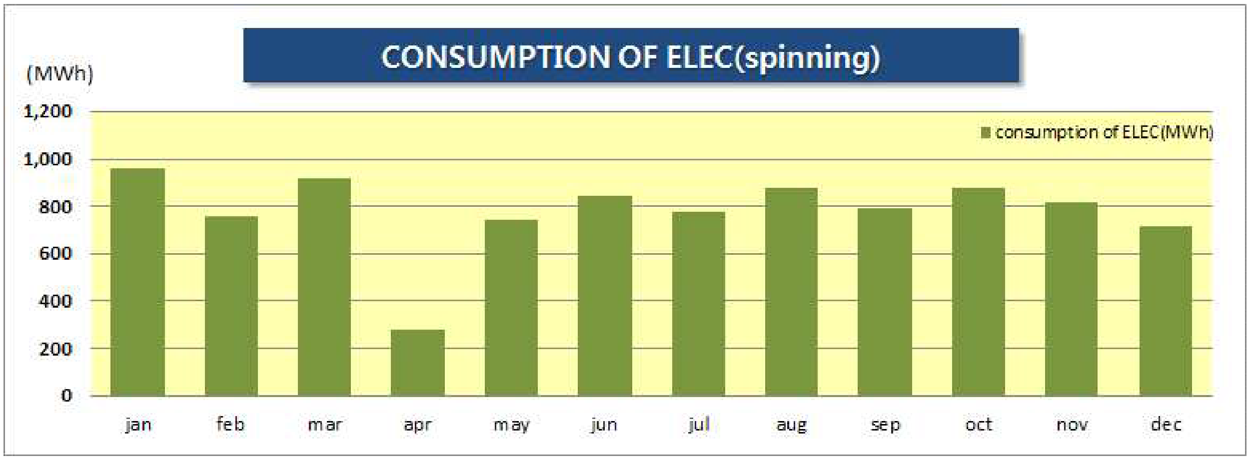


Figure 3-14: Electric power consumption by spinning department

**d. Electric Energy Consumption in Barhol (leather factory)**

Table 3-6: Electric power consumption in barhol (leather factory)

| Month | Receiving power(kwh) | Total electric cost (birr) | Cost($) |
|---|---|---|---|
| Jan | 45,300 | 45,301 | 1,617.89 |
| Feb | 40,020 | 40,021 | 1,429.32 |
| Mar | 39,960 | 39,961 | 1,427.2 |
| Apr | 33,720 | 33,721 | 1,204.32 |
| May | 22,260 | 22,261 | 795 |
| Jun | 18,420 | 18,421 | 657.89 |
| Jul | 27,360 | 27,361 | 977.2 |
| Aug | 38,580 | 38,581 | 1,377.89 |
| Sep | 49,260 | 49,261 | 1,759.32 |
| Oct | 61,500 | 61,501 | 2,196.46 |
| Nov | 34,140 | 34,141 | 1,219.32 |
| Dec | 39,240 | 39,241 | 1,401.46 |
| total | 449,760 | 449,767 | 16,063.12 |


Figure 3-15: Electric power consumption in barhol department

## 3.2. Cost of energy use status and energy use rate of Quiha Maa Garment and Textile Factory

Table 3-7: Cost of Energy use status and rate in 2018 Gc.

| Section | Amount of consumption | Average unit price in 2018 G.C | Cost(birr) in 2018G.C | Cost ($) | Energy use cost rate |
|---|---|---|---|---|---|
| Fuel energy | 893,130L = 804.71 toe | 17 birr/L | 15,183,210 | 542,257.5 | 61% |
| Electric Power | 11,605,260 kwh = 2669.21toe | 0.5778birr/kwh | 6,705,519.3 | 239,482.83 | 39% |
| Total | 3473.92 toe | | 21,888,729.3 | 781,740.33 | 100% |

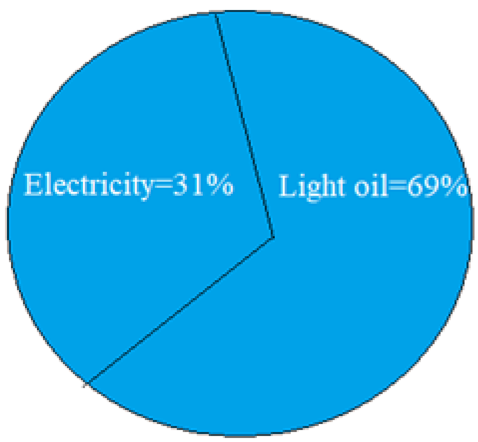


Figure 3-16: Energy use rate in year 2018G.C

$$\text{Energy use cost rate of E. power} = \frac{\text{cost of electric power(birr)}}{\text{total cost of energy use(birr)}} * 100\% \quad (3.3)$$

$$= \frac{6705519.3(\text{birr})}{21{,}888{,}729.3(\text{birr})} * 100\% = 31\%$$

$$\text{Energy use cost rate of fuel} = \frac{\text{cost of fuel(birr)}}{\text{total cost of energy use(birr)}} * 100\% \quad (3.4)$$

$$= \frac{15{,}183{,}210(\text{birr})}{21{,}888{,}729.3(\text{birr})} * 100\% = 69\%$$

## 3.3. Production Status of Quiha Maa Garment and Textile Factory

Table 3-8: Production status of the factory

| section | unit | in year 2018 |
|---|---|---|
| spinning | kg | 1,653,609 |
| knitting | kg | 1,234,640 |
| dyeing | kg | 1,056,647 |
| garment | kg | 3,068,797 |

## 3.4. Components and their present status

**Boiler**

There are installed two boilers (BN1and BN2) at Maa-Garment and Textile Factory. They are operated for supplying steam to dyeing machine. Total annual fuel consumption of boiler1 and 2 is 535,969(l/yr). Boiler facility status and installation view are like below table 3-9 and figure 3-8

Table 3-9: Boiler facility status

| Section | unit | boiler1 | boiler 2 |
|---|---|---|---|
| Type | - | smoke tube | smoke tube |
| Capacity | kg/h | 3,000 | 3,000 |
| Maximum using pressure | kg/cm2 | 12 | 12 |
| Usual using pressure | kg/cm2 | 8.5 | 8.5 |
| Annual fuel consumption | l/yr | 267984.5 | 267984.5 |
| Installation year | year | 2001 | 2001 |
| Maker | - | Ferrolia | Ferrolia |

## Overview of the existing boilers structure

Figure 3-17: Boiler installation view of Quiha Maa Garment and Textile Factory

## Result of measurement of Boiler

Table 3-10: Result of measurement of boiler

| Check item | | Symbol | Unit | Value | Standards |
|---|---|---|---|---|---|
| Ambient temp. | | To | °C | 27.0 | LHV(low heating value) 10,000kcal/kg |
| Indoor temp. | | Tr | °C | 28.0 | |
| fuel | Kind of fuel | - | - | Light oil | Specific gravity 0.83 |
| | Combustion amount | Vt | l/h | 90.8 | |
| | Temp. at feed flow meter | Tf1 | °C | 25.0 | Specific heat 0.45 |
| | Temp. at burner inlet | Tf2 | °C | 25.0 | |
| BFW | Feed water amount | W1L | l/h | 1,081.7 | |
| | Temp. at BLR inlet | Tw | °C | 69.0 | |
| Steam | Flow rate | W2kg | kg/h | 1,058.2 | |
| | 'Pressure at drum | Ps | atg | 8.6 | |
| | Temperature at burner | Ta3 | °C | 28.0 | Specific heat 0.31 |
| Flue gas | Oxygen | (O2) | Vol % | 6.9 | Specific heat 0.33 |
| | Temperature | T | °C | 208 | |

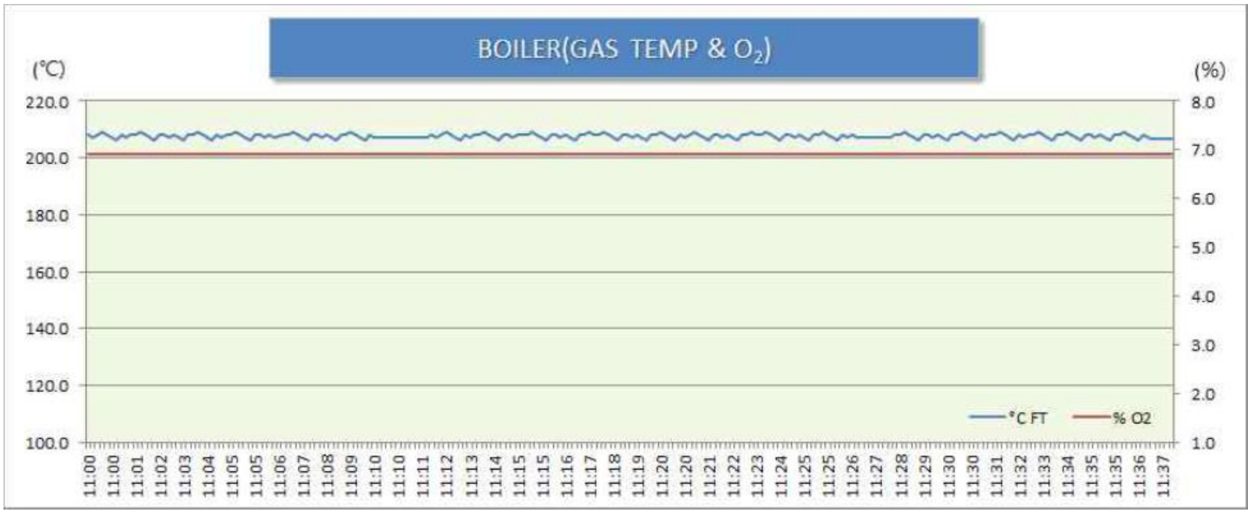


Figure 3-18: Result of flue gas measurements (temperature and %O2)

### Thermo Boiler

#### Thermo Boiler operating status and present condition

There is installed one thermo-boiler at Maa Garment and Textile Factory and it is operated for supplying thermo-oil to dryer and stenter. Its annual fuel consumption is 357,312 l/yr.

Table 3-11: Thermo boiler facility status

| section | unit | thermo boiler |
|---|---|---|
| type | - | smoke tube |
| capacity | kcal/h | 2,000,000 |
| Maximum using pressure | $kg/cm^2$ | 21 |
| usual using pressure | $kg/cm^2$ | 10 |
| circulation flow rate | $m^3/h$ | 90.512 |
| installation year | year | 2001 |

Table 3-12: Result of measurement of Thermo Boiler

| Check Item | Symbol | Unit | Value | standards |
|---|---|---|---|---|
| Ambient temperature | To | ℃ | 27.0 | LHV 10,000kcal/l |
| Indoor temperature | Tr | ℃ | 28.0 | |

| | | | | | |
|---|---|---|---|---|---|
| Fuel | kind of Fuel | - | - | Light oil | Specific gravity 0.83 |
| | combustion Amount | Vt | l/h | 59.3 | |
| | temperature at feed flow meter | Tf1 | °C | 25 | Specific heat 0.83 |
| | temperature at burner inlet | Tf2 | °C | 25 | |
| Kind of thermo-oil | | | Texathermic46 | | |
| Circulation flow rate of thermo-oil | | W1 | $m^3/h$ | 90.512 | |
| Entrance | Thermo-oil temperature | W1L | °C | 221 | |
| | thermo-oil specific heat | | kcal/kg°C | 0.621 | |
| | thermo-oil specific gravity | Tw | $kg/m^2$ | 737 | |
| Output | thermo-oil temperature | W1L | °C | 230 | |
| | thermo-oil specific heat | | kcal/kg°C | 0.630 | |
| | thermo-oil specific gravity | Tw | $kg/m^2$ | 732 | |
| Combustion air | entrance temperature to burner | Ta1 | °C | 28 | Specific Heat 0.318 |
| | temperature before combustion | Ta2 | °C | 28 | |
| output | temperature at BLR body outlet = flue gas temperature | Tg1 | °C | 257 | Specific Heat 0.33 |

**Thermo Boiler installation view**

Figure 3-19: Thermo boiler installation view

## Air Compressor

## Air Compressor present condition

The purpose of air compressor is to give a cool air to the room then if the hot air removes from the machines entering again, the energy needed by the air compressor to cool this hot air is high. There are installed nine air compressors for compressed or suck air using at process of Maa-Garment and Textile Factory. Compressor facility status and installation view are like below table 3-13 and figure 3-11. The amount of air compressed by the air compress is due to rotation of motor.

Table 3-13: Air compressor facility status

| Section | | Motor (kw) | Average (kw) | Flow $m^3$/min | Pressure (Mpa) | Remarks |
|---|---|---|---|---|---|---|
| Spinning and knitting | Comp 1 | 122 | 99.12 | - | 13.8(bar) | On operating |
| | Comp 2 | 15 | - | 2.27 | 0.98 | Not operating |
| | Comp 3 | 15 | 16.15 | 2.27 | 0.98 | On operating |
| | Comp 4 | 15 | - | 2.27 | 0.98 | Not operating |
| | Comp 5 | 15 | 4.46 | 2.27 | 0.98 | On operating |
| | Comp 6 | 15 | - | 2.27 | 0.98 | Not operating |
| dyeing | Comp 1 | 11 | 9.74 | 1.47 | 0.98 | On operating |
| | Comp 2 | 11 | - | 1.47 | 0.98 | Not operating |
| | Comp 3 | 15 | - | - | 10(bar) | Not operating |


Figure 3-20: Air compressors installation view

# CHAPTER FOUR

## QUIHA MAA GARMENT AND TEXTILE FACTORY: MAIN COMPONENTS, ASSOCIATED PROBLEMS AND SOLUTIOS

The main components, associated problems and possible solutions are discussed in this chapter as follows.

## 4.1. Boiler

The basic operating principle of boiler is very simple and easy to understand. The boiler is actually a closed vessel inside which water is stored. Fuel is burned in a furnace and hot gasses are generated. These hot gasses touch with water container where the heat of these hot gases move to the water and consequently steam is generated in the boiler.

**Boiler performance results**

Boiler performance results by Korea Industry Standard of boiler (KSB–6205) heat balance method and flue gas measurement (%O2 in flue gas, and temperature of flue gas) results are like below table 4-1 that operating currently at Maa- Garment and Textile Factory.

Table 4-1: Maa-Garment boiler performance results

| Section | | unit | boiler |
|---|---|---|---|
| Load | | % | 35.3 |
| Efficiency | | % | 77.1 |
| Flue gas | Temperature | °C | 208 |
| | Oxygen | % | 6.9 |
| | Air ratio | - | 1.489 |

**Problem of Boiler**

The problem of boiler according to KSB-6205 heat balance method is high air ratio 1.489 and higher flue gas temperature 208℃ resulted from measurement using flue gas analyzer and under load. Due to these problems the efficiency of the boiler is less than the standard value. The two variables which resolute the burner efficiency are un burnt fuel quantities and excess oxygen levels in the exhaust. As the quantity of excess air is increased, the quantity of un burnt fuel in the exhaust decreases. This results in lowering the un burnt fuel losses but elevating the enthalpy losses. The standard efficiency of oil boiler is 85% and above. But as you seen in the above table boiler efficiency is 77.1% which is below the standard value therefore this can be improved and maintained through making improvements which results in increase efficiency.

The six methods used to improve boiler efficiency are:

- Compute a flue gas investigation on the boiler every two months to evaluate for fuel or air ratio settings and situation air/fuel ratio to enhance efficiency. A high flue gas temperature often reflects the existence of deposits and fouling (accumulation of unwanted material) on the fire and or water side(s) of the boiler. The resulting loss in boiler efficiency can be closely estimated on the basis that a 1% efficiency loss occurs with every 40°F (4.4 °C) increase in stack temperature.
- After an overhaul of the boiler, run the boiler and reexamine the tubes for clean lines after thirty days of operation. The collected quantity of grit will form the criterion as to the necessary frequency of boiler tube cleaning.
- Examine the burner head and orifice once a week and clean if necessary.
- Examine all controls regularly and keep them clean and dry. For water tube boilers burning coal or oil, burst the grit out once a day.
- Purity of water used for steam generation is excessively necessary. It is not normally feasible to use unprocessed waters found in nature as boiler feed water as there are many impurities. Water must be regulated to avoid the impurities or convert them into safe. Other means to avoid contamination and buildup from boilers is a systematic removal by blow down. This way an enormous collection of solids is prevented. Water prescription avoids the formation of scale and dirt deposits on the internal surfaces of boilers. Scale formations severely slowdown the heat flow and cause overheating of metal parts. The

frequency and amount of blow down depend upon the amount and condition of the feed-water.

- Check the operation of the blow down system and make sure that excessive blow down does not occur. Normally, blow down should be no more than 1% to 3% of steam output.

**Calculation of Boiler Efficiency**

There are two methods for calculating boiler efficiency those are direct and indirect methods.

The overall boiler efficiency depends on many parameters apart from combustion and thermal efficiencies. These other variables include on-off losses, radiation losses, and convection losses and blow down losses etc. Steam boiler efficiency depends upon the capacity of boiler used.

1. **Direct method** [1][19]

This method computes the boiler efficiency by using the basic efficiency formula:

$$\eta = \frac{\text{Eout}}{\text{Ein}} * 100\% = \frac{\text{out put heat}}{\text{input heat}} * 100\% \quad (4.1)$$

Eout is the output energy needed to change feed water entering the boiler at a specific pressure and temperature to steam leaving the boiler at a specific pressure and temperature. (This includes the energy take up by the blow down and not converted into steam). Ein is the input energy (heat) into the boiler. The input heat is based on the highest heat or gross calorific value of fuel for efficiency computation in US, UK and in other countries. But Germany based on low heat or net calorific value suggested that for the same boilers, the expressed efficiency will be higher.

or $\eta = \text{Q} * \left[\frac{(\text{H}-\text{h})}{(q*GCV)}\right] * 100\%$. This does not tell the areas where the losses are occurred.

Where, Q= Quantity of steam generated (kg/hr), H= Enthalpy of steam (Kcal/kg)

h= Enthalpy of feed water (kcal/kg), q= quantity of fuel used per hour (kg/hr)

GC= Gross calorific value of fuel = 138.79kcal/kg.

2. **Indirect method** of calculating boiler efficiency [1][19]

$$\%\,\eta = 100 - \text{sum of losses} \quad (4.2)$$

**Comparison between direct and indirect method**

Both the methods of computing boiler efficiency mentioned above have some importance and some necessity related with them. The greatest advantage of indirect method is that it also tells about the sources of losses. By discovering indirect efficiency, one can come to understand where the losses are increased and can be decreased. On other way, direct efficiency values are near to the accurate as compared to indirect efficiency on account of reveal losses such as radiation losses, ON-OFF losses etc. But direct efficiency can only show about the magnitude of overall loss. No information about individual losses and their magnitudes is taking from direct efficiency calculation. Indirect efficiency is evaluated at a specific time but direct efficiency is evaluated in a full time of operation and consequently; wastes on illustration of fluctuating loads, boiler on-off are also taken in calculation.

**Improvement Plan 1: Boiler Air Ratio Control**

The improvement plan is controlling the air ratio of boiler to operate within in standard limit (1.2) to reduce fuel consumption. The method used to decrease air ratio is decreasing the excess air entering to combustion process. That is to get standard air ratio we must decrease the excess air entering to the combustion, then to decrease this excess air we must decrease the capacity of air blower motor because the blower motor revolves blower, which absorb air from one side and toss it on other side of the blower fan. Other methods that can be used to optimize or minimize the excess air entering are changing automatic oxygen control set points, periodic tuning of single set point control mechanisms, installing automatic flue gas monitoring and control, fixing broken baffles and repairing air leaks into the boiler[17].

Percentage of excess air: - is the amount of air above the stoichiometric requirement for complete combustion that is the air used is above the standard value for complete combustion process. If combustion of a stoichiometric mixture is complete there is no fuel and oxygen in flue gas but if there is excess air there is oxygen and if there is excess fuel there is un burnt fuel in the flue gas. Example when air equals to 79%N + 16%$O_2$ the reaction $CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2$ does not produce oxygen and fuel in the output but if $O_2$ is not equal to16% and $N_2$ is not equal to 78% there is oxygen in the output(in flue gas). The stoichiometric air-fuel ratio can be explained as the ratio of amount air needed for full combustion of 1 kg of fuel. It is also known as chemically correct air-fuel ratio. If the combustion is complete then the only maximum heat is available from a given fuel. When there is more than can be used air in the combustion process, extra fuel is burned to increase the temperature of this excess air to that of the combustion process. Excess air is a costly waste of fuel because it simply suck heat that go up the stack, rather than into the process.

The regulation of excess air provides:

- A better boiler heat transfer rate
- Substantial savings on fuel
- It gives warning of flue gas problems (excess air is coming above the maximum efficiency it can produce)

Excess oxygen: - is the quantity of oxygen in the incoming air not used directly during combustion process and is associated to percentage excess air. For example, 15% excess air equals 3% oxygen when natural gas is burning.

Boiler air ratio is managed by Energy Management Standard as below table 4-2 by Korea standard of boiler (KSB-6205).

Table 4-2: KSB-6205 Standard and goal of air ratio of boiler

| Section | Load (%) | Air ratio | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Solid fuel | | Liquid fuel | | Gas fuel | | shaft furnace gas, sub generating gas etc. | |
| | | standard | goal | standard | goal | standard | goal | standard | goal |
| for large generation | 75-100 | 1.15-1.25 | 1.1-1.2 | 1.1-1.2 | 1.05-1.15 | 1.05-1.15 | 1.05-1.1 | 1.2-1.25 | 1.15-1.2 |
| over 20 t/h generation | 50-100 | 1.2-1.3 | 1.15-1.25 | 1.15-1.25 | 1.1-1.2 | 1.1-1.2 | 1.05-1.15 | 1.2-1.3 | 1.2-1.3 |
| over 5 t/h below 20 t/h generation | 50-100 | 1.25-1.35 | - | 1.2-1.3 | 1.15-1.25 | 1.15-1.25 | 1.1-1.2 | - | - |
| below 5 t/h generation | 50-100 | 1.4-1.45 | - | 1.2-1.3 | 1.2-1.25 | 1.3-1.4 | 1.15-1.25 | - | - |

- Basic calculation standards [18][19]

a) Percentage of excess air supplied (EA)

$$EA = \left[\frac{\%\ O_2 \text{ in flue gas by volume}}{\%\ O_2 \text{ content in air} - \%\ O_2 \text{ in flue gas by volume}}\right] * 100\% \qquad (4.1.1)$$

$$EA = \left[\frac{6.9}{21-6.9}\right] * 100\% = 48.94\% \approx 49\%$$

A well-designed burner will operate with as little as 5 to 15% excess air, while converting all combustibles in the fuel to useful energy [35]. But here the excess air is 48.94≈ 49% which is three times higher than the standard therefore air ratio control is mandatory. Reducing excess air by 5- 15% and reducing in stack temperature by 40°F (4.4°C) increase boiler efficiency by 1% and results in energy saving of 5-25% [44].

b) Fuel consumption (F)

$$F = \text{fuel combustion amount}\left(\frac{\text{l}}{\text{hr}}\right) * \text{specific gravity} * \text{volume collection coefficient} \quad (4.1.2)$$

$$F = 90.8 * 0.83 * 0.9754 = 75.4\text{kg/hr}$$

Where volume collection coefficient is 0.9754 litters from standards

c) Charged boiler feed water ($W_1$kg) = steam flow rate of boiler

$$W_1(\text{kg}) = \frac{\text{amount of BFW}\left(\frac{\text{l}}{\text{hr}}\right)}{\text{specific volume of feed water}\left(\frac{\text{l}}{\text{kg}}\right)} \quad (4.1.3)$$

$$W_1(\text{kg}) = \frac{1081.7}{1.02225} = 1058.2\text{kg/hr}$$

d) Flow rate of BFW per unit fuel ($w_1$)

From equation (4.1.1) and (4.1.2) the flow rate of BFW per unit fuel can be calculated as

$$w_1 = \frac{\text{charged BFW}\left(\frac{\text{kg}}{\text{hr}}\right)}{\text{fuel consumption}\left(\frac{\text{kg}}{\text{hr}}\right)} \quad (4.1.4)$$

$$w_1 = \frac{1058.2}{75.4} = 14.03$$

e) Generated steam flow rate ($W_2$kg)

$$W_2(\text{kg}) = \text{flowrate of steam}\left(\frac{\text{kg}}{\text{hr}}\right) - \text{amount of blow down}\left(\frac{\text{kg}}{\text{hr}}\right) \quad (4.1.5)$$

$$W_2(\text{kg}) = 1058.2 - 0.0 = 1058.2\text{kg/hr}$$

f) Air ratio (m)

$$m = \left[\frac{\%\ O_2 \text{ in air}}{(\ \%\ O_2 \text{ in air} - \%\ O_2 \text{ combustion})}\right] \quad (4.1.6)$$

$$m = \left[\frac{21}{(21 - 6.9)}\right] = 1.49$$

g) Theoretical combustion air flow rate (Ao)

$$A_O = \left[\frac{12.38 * \text{combustion heat of fuel}}{\text{light oil low heat value}}\right] - 1.36 \qquad (4.1.7)$$

$$A_O = \left\{\frac{12.38 * \text{HL}}{10{,}000}\right\} - 1.36 = \left\{\frac{12.38 * 10{,}000}{10{,}000}\right\} - 1.36 = 11.02\text{Nm3/kg}$$

h) Theoretical flue gas flow rate (Go)

$$G_O = \left\{\frac{15.75 * \text{combustion heat of fuel}}{\text{light oil low heat value}}\right\} - 3.91 \qquad (4.1.8)$$

$$G_O = \left\{\frac{15.75 * \text{HL}}{10{,}000}\right\} - 3.91 = \left\{\frac{15.75 * 10{,}000}{10{,}000}\right\} - 3.91 = 11.84\text{Nm3/kg}$$

The value 3.91 indicates the amount of heat absorbed at furnace during the combustion.

2. Heat input

a) Combustion heat of fuel (HL)

$H_L$= 10,000 kcal/kg-fuel [amount of heat produced during combustion by burning of 1kg of fuel]

b) Sensible heat of fuel ($Q_1$) (heat of fuel due to atmospheric condition)

$$Q_1 = \text{specfic heat of fuel} * (\text{temp at burner inlet} - \text{ambient temp}) \qquad (4.1.9)$$

$$Q_1 = 0.45 * (25 - 27) = -0.9\text{kcal/kg}$$

c) Sensible heat of combustion air (Q2)[heat of air due to atmospheric condition]

$$Q_2 = \text{theoretical combustion air flow rate} * \text{air ratio} * \text{specific heat of air} * (\text{indoor temperature} - \text{ambient temperature}) \qquad (4.1.10)$$

$$Q_2 = 11.02 * 1.49 * 0.31 * (28 - 27) = 5.1\text{kcal/kg}$$

d) Heat input by atomizing steam ($Q_3$)( heat input in case of one boiler supply steam to other boiler)

$$Q_3 = \text{atomizing steam flow rate per 1kg fuel} * (\text{atomizing steam enthalpy} - \text{ambient temperature enthalpy}) \qquad (4.1.11)$$

$Q_3 = 0.0 * (690.1 - 27) = 0.0\text{kcal/kg}$ [because no one boiler supply to other boiler]

e) Total heat of input (Qi)

$$Q_I = H_L + Q_1 + Q_2 + Q_3 \qquad (4.1.12)$$

$$Q_i = 10{,}000 - 0.9 + 5.1 + 0.0 = 10{,}004.2\text{kcal/kg}$$

3. Heat output

a) Heat of steam generating ($Q_S$)

$$Q_S = \text{flow rate of steam per unit fuel}\left(\frac{\text{kcal}}{\text{kg}}\right)$$

$$* \left(\text{wet steam enthalpy} - \text{BFW enthalpy}\right)\left(\frac{\text{kcal}}{\text{kg}}\right) \quad (4.1.13)$$

$Q_S = 14.034 * (652.87 - 69) = 7719\text{kcal/kg} - \text{fuel}$, BFW enthalpy = BFW temp at BLR inlet

Wet steam enthalpy (hx) = sensible heat of feed water + (latent heat * steam dryness)

hx = 179.399 + (483.13 * 0.98) = 652.87 kcal/kg – fuel,

b) Heat loss by flue gas ($L_1$)

$$L_1 = \text{flow rate of flue gas} * \text{specific heat}$$

$$* \left(\text{temperature of flue gas outlet} - \text{ambient temperature}\right) \quad (4.1.14)$$

$$L_1 = 11.84\text{N}m^3/\text{kg} * 0.33 * (208 - 27) = 937.2 \text{ kcal/kg}$$

c) Heat loss by atomizing steam ($L_2$)

$$L_2 = \text{atomizing steam flow rate} * \left(\text{gas temp} - \text{feed water enthalpy}\right) \quad (4.1.15)$$

$$L_2 = 0.0 * (690.6 - 69) = 0.0\text{kcal/kg}.$$

super steam or gas enthalpy at flue gas temperature of 208 ℃ is 690.6 kcal/kg[standard] and atomizing steam flow rate equals to zero because no one boiler is supply steam to other boiler.

d) Heat loss by partial combustion ($L_3$)

$$L_3 = 30.5 * \{\text{theo flue gas} + (\text{air ratio} - 1) * \text{theo comb air}\} * \text{co\%} \quad (4.1.16)$$

$30.5 * \{11.84 + (1.49 - 1) * 11.02\} * 0.0 = 0.0\text{kcal/kg}$. 30.5kcal/kg indicates the amount of heat produced in 1kg of fuel during partial combustion. %co = 0, no co loss during partial.

e) Heat loss by continuous blow down

$$H_{lcbd} = \text{blow down per unit fuel}\left(\frac{\text{kg}}{\text{N}m^3}\right)$$

$$* \left\{\text{blow down water enthalpy} - \text{feed water enthalpy}\left(\frac{\text{kcal}}{\text{kg}}\right)\right\} \quad (4.1.17)$$

$H_{lcbd} = 0.0 * (690.6 - 69) = 0.0\text{kcal/kg}$ Because during indirect process blow down is closed then no heat loss occur. Blow down water means water which is with impurities removed out.

f) Heat loss due to radiation, convection, transfer of heat and others (L4)

$$L_4 = Q_i - (Q_S + L_1 + L_2 + L_3) \quad (4.1.18)$$

$$L_4 = 10004.2 - (7719 + 707.2 + 0 + 0) = 1578\text{kcal/kg}$$

g) Total heat output ($L_i$)

$$L_i = \text{heat input} - \text{total heat losses} \tag{4.1.19}$$

$$L_i = \text{Qi} - (\text{L1} + \text{L2} + \text{L3} + \text{L4})$$

$$L_i = 10004.2 - (707.2 + 0 + 0 + 1578) = 7719\text{kcal/kg}$$

h) Total heat loss (L)

$$\text{L} = \text{heat input} - \text{total heat output} = \text{sum of losses} \tag{4.1.20}$$

$$\text{L} = Q_i - L_i = L_1 + L_2 + L_3 + L_4$$

$$\text{L} = (10004.2 - 7719) = 707.2 + 0 + 0 + 1578 = 2285.2\ \text{kcal/kg}$$

4. Performance data of the existing boiler

a) Load rate of boiler ($L_f$)

$$L_f = \left(\frac{\text{steam flow rate}}{\text{max steam flow rate}}\right) * 100\% \tag{4.1.21}$$

$$L_f = \frac{1058.2\text{kg/h}}{2997.74\text{kg/h}} * 100\% = 35.3\%$$

which is under rated load, here maximum steam flow rate is the maximum rate that the boiler can generate during manufacturing and steam flow rate means the factory boiler steam generating capacity now therefore the boiler generating steam is under standard.

b) Boiler efficiency (η)

1. Indirect method: -

$$\text{boiler efficiency}(\eta) = 100 - \text{sum of heat losses} \tag{4.1.22}$$

$$\eta = 100 - (L_1 + L_2 + L_3 + L_4)$$

$$\eta = 100 - (7.072 + 0 + 0 + 15.78) = 77.1\%$$

This is below standard value, where $L_1$, $L_2$, $L_3$&$L_4$ are heat losses

2. Direct method: $\text{boiler efficiency}(\eta) = (\frac{\text{heat output}}{\text{heat input}}) * 100\%$

$$\eta = \left(\frac{7719}{10004.2}\right) * 100\% = 77.1\%.$$

Here the reason for low boiler efficiency is higher air ratio, high flue gas temperature and under load of boiler which results to high heat loss.

c) Equivalent amount of steam generated per hour ($W_e$)

$$W_e = \frac{\text{steam flow rate per hour}\left(\frac{\text{kg}}{\text{hr}}\right) * (\text{steam enthalpy} - \text{BFW enthalpy})}{\text{latent heat}} \tag{4.1.23}$$

$$W_e = \frac{[1058.2 * (652.87 - 69)]}{539\text{kcal/kg}} = 969.6\text{kg/hr}$$

d) Equivalent ratio of steam generated per fuel ($R_e$)

$$R_e = \frac{\text{equivalent amount of steam generated per hour}\left(\frac{\text{kg}}{\text{hr}}\right)}{\text{fuel consumption}(\frac{\text{kg}}{\text{hr}})} \quad (4.1.24)$$

$$R_e = \frac{969.6}{75.4} = 12.86$$

e) Heat load of boiler heat transfer surface ($H_b$)

$$H_b = \frac{\{\text{generating flow rate} * (\text{steam enthalpy} - \text{feed water enthalpy})\}}{\text{heat transfer surface}} \quad (4.1.25)$$

$$H_b = \frac{7369.8 * (647.21 - 92)}{1043.24} = 3922.2\text{kcal}/m^2\text{h}$$

f) Equivalent evaporation ratio of boiler heat transfer surface ($B_e$)

$$B_e = \frac{\text{generating flow rate} * (\text{steam enthalpy} - \text{feed water enthalpy})}{539 * \text{heat transfer surface}} \quad (4.1.26)$$

$$B_e = \frac{7369.8(647.21 - 92)}{539 * 1043.24} = 7.28\text{kg}/m^2\text{hr}$$

**Expected Results**

Table 4-3: Variables used in calculation of boiler performance

| | | | |
|---|---|---|---|
| $m_1$ | = | current air ratio | 1.489 |
| $m_2$ | = | standard theoretical combustion air ratio | 1.2 |
| $A_0$ | = | theoretical combustion air flow rate | 11.02($Nm^3$/kg) |
| $C_a$ | = | air average specific heat | 0.31(kcal/$Nm^3$°C) |
| $Q_i$ | = | low heat value | 10,000(kcal/kg) |
| $t_g$ | = | flue gas temperature | 208(°C) |
| $t_a$ | = | combustion air temperature | 28(°C) |
| Fuel consumption | = | 535,969 l/yr | |
| Fuel unit price | = | 17 birr/l | |

a) Heat recovery (Q)

$$Q = (m_1 - m_2) * Ao * Ca * (tg - ta) \quad (4.1.27)$$

$$Q = (1.489 - 1.2) * 11.02 * 0.31 * (208 - 28) = 178 \text{ kcal/kg}$$

b) Heat reduction rate (E)

$$E = \left(\frac{\text{heat recovery}}{\text{low heat value}}\right) * 100\% \quad (4.1.28)$$

$$E = \frac{Q}{Q_i} * 100\% = \frac{178}{10{,}000} * 100\% = 1.8\%$$

c) Annual fuel saving

$$AFS = \text{annual fuel consumption}\left(\frac{l}{yr}\right) * \text{reduction rate}(\%) \quad (4.1.29)$$

$$AFS = 535969\left(\frac{l}{yr}\right) * 1.8 = 9647\left(\frac{l}{yr}\right) = 8.692\text{toe/yr}$$

d) Total energy reduction rate

$$TERR = \left\{\frac{\text{annual fuel saving}\left(\frac{l}{yr}\right)}{\text{annual energy consumption}\left(\frac{l}{yr}\right)}\right\} * 100\% \quad (4.1.30)$$

$$TERR = \frac{9647}{535{,}969} * 100\% = 1.8\%$$

e) Greenhouse gas reduction

$$GGR = \text{annual fuel saving}\left(\frac{toe}{yr}\right) * \text{light oil C emission coefficient}\left(\frac{tc}{toe}\right) \quad (4.1.31)$$

$$GGR = 8.692\left(\frac{toe}{yr}\right) * 0.846\left(\frac{tc}{toe}\right) = 7.35 \text{ tc/yr}$$

a) Annual cost savings

$$ACS = \text{annual fuel reduction}\left(\frac{l}{yr}\right) * \text{fuel unit price}\left(\frac{birr}{l}\right) \quad (4.1.32)$$

$$ACS = 9647\left(\frac{l}{yr}\right) * 17\text{birr/l} = 163{,}999\text{birr/yr} = \$5857.1$$

b) Investment cost = [16,600 = cost of air blower motor = $500+labor cost (Birr)]

c) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{birr}{yr})} \quad (4.1.33)$$

$$P_b = \frac{16,600\text{birr}}{163,999\text{birr/yr}} = 0.10 \text{ yr}$$

**Improvement Plan 2: Boiler Flue Gas Waste Heat Recovery**

The improvement plan is boiler efficiency rising and fuel consumption reduction plan by feed water preheating through boiler flue gas waste heat recovery by installing economizer. For existing installations where, the flue gas temperatures exceed a limit of approximately 230°F for natural gas and 270°F (132℃) for fuel oil, heat recuperation is an option [17]. Therefore the flue gas temperature of the boiler is 208℃ then flue gas waste heat recovery is necessary to save energy, cost and reduce carbon emission. Heat recovery systems are implemented to make use of some of the energy which otherwise would be loss into the atmosphere. The system use a hot media leaving the process to preheat other, or sometimes the same, media entering the process thus energy otherwise lost does useful work.

**Flue gas**: - is a mixture of gases formed by the heating of fuel or other materials in power stations and industrial factories and takes out or removed through tube. The temperature of the flue gas shows how much energy is loss to the atmosphere.

Or flue gas is the gas exiting in the atmosphere via a flue, which is a pipe or channel for conveying exhaust gases from a fireplace, oven, furnace, boiler or steam generator. Quite often, the flue gas refers to the combustion exhaust gas produced at power plants and industries [1].

**An Economizer: -** is a heat exchanger that apprehends waste heat from the flue gas and moves it to the boiler feed water. That is the purpose of an economizer is to increase boiler efficiency by recovering the heat that would otherwise be lost in the form of flue gas and use it to heat the water. Because the heat recovered from flue gas covers the energy (fuel) needed to heat the water. An Economizer is air to liquid heat exchanger its main working principle is to preheat boiler feed water. It may also be used to heat process or domestic water, or to provide hot liquids for space heating or make-up air heating equipment. The basic working principle is sensible heat is moved from the flue gases to the de-aerated feed water as the liquid flows through a series of tubes in the economizer found in the exhaust stack.

Most economizers have finned tube heat exchangers made of stainless steel while the inlet and outlet tube are carbon steel joined with suitable insulation. The maximum suggested waste gas temperature for standard units is about 1,800°F (982°C). Every 6°C raise in feed water temperature by economizer/waste heat recovery correspond to a 1% saving in fuel consumption. According to economizer manufacturers, fuel consumption is reduced approximately by 1% for each 40°F (4.4°C) reduction in flue gas temperature.

Economizers can often decrease fuel needed by 5% to 10%, with the economizer solution paying for itself in less than two years.

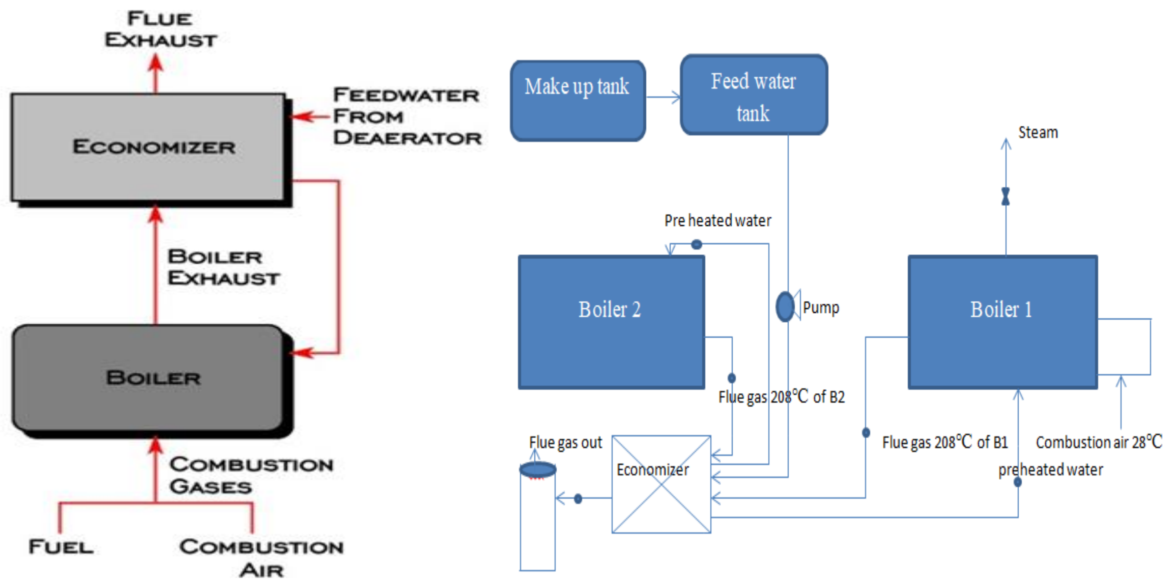


Figure 4-1: Schematic diagram and improved boiler feed water preheater installation plan using Economizer

Table 4-4: Standard and goal of flue gas temperature of boiler

| | Solid fuel | | Liquid fuel | | Gas fuel | | shaft furnace gas, sub generating gas etc | |
|---|---|---|---|---|---|---|---|---|
| | standard | goal | standard | goal | standard | goal | standard | goal |
| for generation | 433{160} | 423{150} | 433{160} | 418{145} | 383{110} | 383{110} | 473{200} | 463{190} |
| over 20 t/h generation | 473{200} | 453{180} | 473{200} | 443{170} | 443{170} | 423{150} | 463{190} | |
| over 5 t/h below 20 t/h generation | 523{250} | 523{250} | 493{220} | 463{190} | 463{190} | 443{170 | - | - |
| below 5 t/h generation | - | - | 443{170} | 400{127} | 493{220} | 473{200} | - | - |

The standard and goal of flue gas temperature of boiler is 170℃ &127℃ respectively for generation below 5t/h. Calculation standards [19]

Table 4-5: Variables used in boiler flue gas waste recovery calculation

| | | | |
|---|---|---|---|
| $m_1$ | = | current air ratio | 1.489 |
| $m_2$ | = | air ratio after control(standard air ratio) | 1.2 |
| $G_0$ | = | theoretical flue gas flow rate(from improvement 1) | 11.84(Nm3/kg) |
| $C_g$ | = | flue gas average specific heat | 0.33(kcal/Nm3°C) |
| $Q_i$ | = | low heat value | 10,000(kcal/kg) |
| $tg_1$ | = | flue gas temp before improve | 208(°C) |
| $tg_2$ | = | flue gas temp after improve=goal | 127(°C) |
| Fuel consumption | = | 535,969(l/yr) | |
| Fuel price | = | 17 birr/l | |

**Expected results**

a) Heat recovery (Q)

$$Q = (m_1 - m_2) * \text{Go} * \text{Cg} * (\text{tg1}tg_1 - tg_2) \quad (4.1.34)$$

$$Q = (1.489 - 1.2) * 11.84 * 0.33 * (208 - 127) = 315\text{kcal/kg}$$

b) Heat reduction rate (E)

$$E = \frac{\text{heat recovery}}{\text{low heat value}} * 100\% \tag{4.1.35}$$

$$E = \frac{Q}{Q_i} * 100\% = \frac{315}{10{,}000} * 100\% = 3.2\% = 0.032$$

c) Annual fuel savings(AFS)

$$AFS = \text{annual fuel consumption} * \text{reduction rate} \tag{4.1.36}$$

$$AFS = 535969 \frac{l}{yr} * 0.032 = 17{,}151\ l/yr$$

$$AFS = 17.151 kl/yr * 0.901 toe/yr = 15.45 toe/yr [\text{light oil conversion standard}]$$

d) Total energy reduction rate (fuel + power)

$$TERR = \left\{ \frac{\text{annual fuel saving}\left(\frac{toe}{yr}\right)}{\text{annual energy consumption}\left(\frac{toe}{yr}\right)} \right\} * 100\% \tag{4.1.37}$$

$$TERR = \{ \frac{15.45\left(\frac{toe}{yr}\right)}{3473.92\left(\frac{toe}{yr}\right)} \} * 100\% = 0.44\%$$

e) Greenhouse gas reduction(GGR)

$$GGR = \text{annual fuel saving}\left(\frac{toe}{yr}\right) * \text{light oil C emission coefficient}\left(\frac{tc}{toe}\right) \tag{4.1.38}$$

$$GGR = 15.45\left(\frac{toe}{yr}\right) * 0.846\left(\frac{tc}{toe}\right) = 13.07 tc/yr$$

f) Annual cost savings(ACS)

$$ACS = \text{annual fuel saving}\left(\frac{l}{yr}\right) * \text{fuel unit price}\left(\frac{birr}{l}\right) \tag{4.1.39}$$

$$ACS = 17{,}151\left(\frac{l}{yr}\right) * 17 birr/l = 291{,}567 birr/yr = \$10413.1$$

g) Investment cost = [$15,000+$600 = 436,800Birr = cost of economizer +labor cost]

h) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{birr}{yr})} \tag{4.1.40}$$

$$P_b = \frac{436{,}800}{291{,}567} = 1.49 yr$$

## 4.2. Thermo Boiler

There is installed one thermo boiler in the factory used for supplying thermo-oil at dryer and stenter.

**Dryer:** - is a machine used to eliminate or reduce the water content of the fibres, yarns and fabrics following wet processes.

**Stenter:** - This machine is used to remove wet fully from the fabric. The fabric is transported through the machine in open width.

A thermal oil boiler fires through a helical coil and creates energy from the hot products of combustion by burning the coil via radiation and convection. The coil burns the thermal oil or fluid that is drive through the thermal oil boiler. The thermal oil burns coils in different types of heat consumers. Unalike a water or steam boiler, this heating process does not deliberately pressurize the system. The high heat thermo oil is circulating from thermo boiler to dryer and stenter and return back to thermo boiler through oil circulation pump to reheat. That is it uses hot oil circulation pump to force liquid to circulate, the heat transfer to the heating equipment (wet cloth at dryer and stenter) and then the heat transfer oil come back to the boiler for heating again.

**Thermo Boiler Performance Results**

Thermo boiler performance result by Korea industry standard KSB–6205 heat balance method and flue gas measurement result are like below table 4-6 that operating currently at Maa Garment and Textile Factory.

Table 4-6: Flue gas and efficiency analysis of thermo boiler

| section | | unit | Thermo Boiler |
|---|---|---|---|
| load | | % | 23 |
| efficiency | | % | 77.6 |
| Flue gas | temperature | °C | 257 |
| | Oxygen | % | 5.9 |
| | Air ratio | - | 1.391 |

**Problem**

From the performance result above the problem of thermo-boiler is higher air ratio 1.391, high flue gas temperature 257°C and under load. The reasons for these problems are high heat loss, excess air and etc. due to these problems the efficiency of the thermo boiler is low at load rate of 23%.

**Improvement Plan 1: Thermo Boiler Air Ratio Control**

The improvement plan is making the thermo boiler to operate within a standard air ratio 1.2 to reduce fuel consumption and increase efficiency. Therefore, to reduce the air ratio we must decrease the excess air entering to the combustion process because when the air entering is excess the fuel required for combustion process is very high to produce high heat. The methods used to reduce air ratio are decreasing excess air by decreasing the capacity of air blower motor, changing automatic oxygen control set point, periodic tuning of single set point control mechanism, installing automatic flue gas monitoring and control, fixing broken baffle's and repairing air leaks in to boiler.

Calculation standards [18] [21]

a) Percentage of excess air supplied (EA)

$$\mathrm{EA} = \left[\frac{\%\, O_2 \text{ in flue gas by volume}}{\%O_2 \text{ content in air} - \%\, O_2 \text{ in flue gas by volume}}\right] * 100\% \qquad (4.2.1)$$

$$\mathrm{EA} = [\frac{5.9}{21 - 5.9}] * 100\% = 39.1\%$$

where EA is 2.5 times above the standard one because the acceptable excess air is 5-15%. Due to this high excess air the efficiency of the thermo boiler is low because when the excess air is higher the fuel needed to burn this excess air is also higher and when the excess air is high heat is absorbed by stack (exhausted gas) rather than by the process.

a) Fuel consumption (F)

$$\mathrm{F} = \text{fuel combustion} * \text{spec gravity} * \text{volume collection coefficient} \qquad (4.2.2)$$

$$\mathrm{F} = 59.3 \text{ l/hr} * 0.83 * 0.9754 = 48.1 \text{kg/hr}$$

b) Air ratio (m)

$$\mathrm{m} = \frac{\%\, O_2 \text{ in air}}{(\%O_2 \text{ in air} - \%\, O_2 \text{ combustion})} \qquad (4.2.3)$$

$$m = \frac{21}{21 - 5.9} = 1.391 \approx 1.4$$

c) Theoretical combustion air flow rate ($A_O$)

$$A_O = \left[\frac{12.38 * \text{combustion heat of fuel}}{\text{light oil low heat value}}\right] - 1.36 \quad (4.2.4)$$

$$A_O = \left[\frac{12.38 * 10{,}000}{10{,}000}\right] - 1.36 = 11.02 \text{ Nm3/kg}$$

d) Theoretical flue gas flow rate ($G_O$)

$$G_O = \left[\frac{15.75 * \text{combustion heat of fuel}}{\text{light oillow heat value}}\right] - 3.91 \quad (4.2.5)$$

$$G_O = \left[\frac{15.75 * 10{,}000}{10{,}000}\right] - 3.91 = 11.84 \text{ Nm3/kg}$$

The value 3.91 indicates the amount of heat absorbed at furnace during combustion

2) Heat input

a) Combustion heat of fuel (HL)

$H_L$= 10,000 kcal/kg

b) Sensible heat of fuel ($Q_1$)

$$Q_1 = \text{spec heat of fuel} * (\text{temp at burner inlet} - \text{ambient temp}) \quad (4.2.6)$$

$$Q_1 = 0.45 * (25 - 27) = -0.9 \text{ kcal/kg}$$

c) Sensible heat of combustion air ($Q_2$)

$$Q_2 = \text{theoretical air flow rate} \left(\frac{\text{N}m^3}{\text{kg}}\right) * \text{air ratio} * \text{specfic heat of combustion air}$$
$$* (\text{temperature before combustion} - \text{ambient temperature}) \quad (4.2.7)$$

$$Q_2 = 11.028 * 1.391 * 0.318(28 - 27) = 4.7 \text{ kcal/kg}$$

d) Total heat input ($Q_i$)

$$Q_i = H_L + Q_1 + Q_2 \quad (4.2.8)$$

$$Q_i = 10{,}000 - 0.9 + 4.7 = 10{,}003.8\text{kcal/kg} = 59.3 * 10{,}003.8\text{kcal/kg} = 593{,}225.3 \text{ kcal/hr}$$

3) Heat output

**a)** Heat of steam generating ($Q_S$)

$$Q_S = 0 \text{ kcal/kg} \quad (4.2.9)$$

$Q_S$ Equals to zero because in thermo boiler no steam is generated it generate high temperature thermo oil this high temperature thermo oil is used at dryer and stenter to dry the wet fabric/yarn.

b) Heat loss by flue gas ($L_1$)

$$L_1 = [\text{theo flue gas flow rate} + (\text{air ratio} - 1) * \text{theo comb air flow rate}] * \text{spec heat} * (\text{flue gas temp} - \text{ambient temp}) \qquad (4.2.10)$$

$$L_1 = \{11.84 + (1.391 - 1) * 11.02\} * 0.33 * (257 - 27) = 1224.9\text{kcal/kg}$$

c) Heat loss by partial combustion ($L_2$)

$$L_2 = (30.5\text{kcal/kg}) * \{\text{theo flue gas} + (\text{air ratio} - 1) * \text{theo comb air}\} * \text{CO\%} \qquad (4.2.11)$$

$$L_2 = 30.5 * \{11.84 + (1.39 - 1) * 11.02\} * 0.0\text{kcal/kg} = 0.0\text{kcal/kg}$$

d) Heat loss by radiation and transfer of heat

$$L_3 = Q_i - (Q_S + L_1 + L_2) \qquad (4.2.12)$$

$$L_3 = 100003.8\left(\frac{\text{kcal}}{\text{kg}}\right) - (0 + 1224.9 + 0) = 1020.4\text{kcal/kg}$$

e) Absorption heat(L4) of thermo-oil boiler is equal with output heat because output heat means the heat out from the thermo boiler used to do work, but the others heats are loses therefore in thermo boiler the output heat is the heat absorbed by the clothes in dryer and stenter to remove wet in fabric/yarn. Therefore Absorption heat of thermo oil boiler (L4) equals to total heat input minus total heat losses equals to output heat

$$L_4 = Q_i - (L_1 + L_2 + L_3) \qquad (4.2.13)$$

$$L_4 = 10003.8\text{kcal/kg} - (1224.9 + 0 + 1020.4) = 7758.5\text{kcal/kg} = 460079.1\text{kcal/hr}$$

f) Total output heat ($L_i$)

$$L_i = \text{heat input} - \text{total heat losses} = \text{absorption heat} \qquad (4.2.14)$$

$$L_i = \text{heat input} - (L_1 + L_2 + L_3)$$

$$\text{Li} = 10003.8 - (1224.9 + 0 + 1020.4) = 7758.5\text{kcal/kg} = 460079.1\text{kcal/hr}$$

g) Total heat loss (L)

$$\text{L} = \text{heat input} - \text{absorption heat} = \text{sum of heat losses} \qquad (4.2.15)$$

$$\text{L} = L_1 + L_2 + L_3 = 1224.9 + 0 + 1020.4 = 2245.3 \text{ kcal/kg}$$

4) Performance data

a) Load rate of thermo boiler ($L_f$)

$$L_f = \left\{\frac{\text{absorption heat of thermo oil boiler}\left(\frac{\text{kcal}}{\text{hr}}\right)}{\text{boiler capacity}\left(\frac{\text{kcal}}{\text{hr}}\right)}\right\} * 100 \qquad (4.2.16)$$

$$L_f = \{\frac{460{,}079.1(\frac{kcal}{hr})}{2{,}000{,}000(\frac{kcal}{hr})}\} * 100 = 23\%$$

Which is under load i.e. thermo boiler supplies heat 23% from the designed standard

b) Efficiency of thermo oil boiler (η)

1. Indirect method:

$$\eta = 100 - (\text{sum of losses}) \quad (4.2.17)$$

η = 100-(12.249 + 0 + 10.20.4) =77.547% ≈ 77.6%

2. Direct method:

$$\eta = \left\{\frac{\text{absorbation heat of thermo oil boiler}\left(\frac{kcal}{kg}\right)}{\text{total heat of input}\left(\frac{kcal}{kg}\right)}\right\} * 100\% = \left(\frac{\text{heat output}}{\text{heat input}}\right)*100\%$$

$$\eta = \left(\frac{7758.5}{10{,}003.8}\right) * 100 = 77.555 \approx 77.6\%$$

c) Circulation flow rate of thermo-oil (W1) (from name plate) = 90.512$m^3$/hr

- Basic Calculation standards [18][21]

Table 4-7: Variables used in thermo oil boiler air ratio control calculations

| | | | |
|---|---|---|---|
| $m_1$ | = | current air ratio | 1.391 |
| $m_2$ | = | standard theoretical combustion air ratio | 1.2 |
| $A_0$ | = | theoretical combustion air flow rate | 11.02($Nm^3$/kg) |
| $C_a$ | = | air average specific heat | 0.31(kcal/$Nm^3$°C) |
| $Q_i$ | = | low heat value | 10,000(kcal/kg) |
| $t_g$ | = | flue gas temperature | 257(°C) |
| $t_a$ | = | combustion air temperature | 28(°C) |
| Fuel consumption | = | 357,312 l/yr. | |
| Fuel unit price | = | birr/l | |

**Expected results**

a) Heat recovery (Q)

$$Q = (m_1 - m_2) * A_O * C_a * (t_g - t_a) \quad (4.2.18)$$

$$Q = (1.391 - 1.2) * 11.02 * 0.31 * (257 - 28) = 149\text{kcal/hr}$$

b) Heat reduction rate (E)

$$E = \frac{\text{heat recovery}}{\text{low heat value}} * 100\% = \frac{Q}{Q_i} * 100\% \quad (4.2.19)$$

$$E = \frac{149}{10{,}000} * 100\% = 1.49\% = 0.0149$$

c) Annual fuel saving/reduction(AFS)

$$\text{AFS} = \text{annual fuel cosumption}\left(\frac{l}{yr}\right) * \text{reduction rate} \quad (4.2.20)$$

$$\text{AFS} = 357312\frac{l}{yr} * 0.0149 = 5323.95\frac{l}{yr} = 5.32395\frac{kl}{yr} = 4.797\ \text{toe/yr}$$

d) Total energy reduction rate(TERR)

$$\text{TERR} = \left\{\frac{\text{annual fuel saving}\left(\frac{toe}{yr}\right)}{\text{annual energy consumption(fuel + power)}}\right\} * 100\% \quad (4.2.21)$$

$$\text{TERR} = \{\frac{4.797\left(\frac{toe}{yr}\right)}{3473.92\left(\frac{toe}{yr}\right)}\} * 100\% = 0.14\%$$

e) Greenhouse gas reduction(GGR)

$$\text{GGR} = \text{annual fuel saving} * \text{light oil C emission coefficient} \quad (4.2.22)$$

$$\text{GGR} = 4.797\left(\frac{toe}{yr}\right) * 0.846\left(\frac{tc}{toe}\right) = 4.05\text{tc/yr}$$

f) Annual cost savings(ACS)

$$\text{ACS} = \text{annual fuel reduction}\left(\frac{l}{yr}\right) * \text{fuel unit price}\left(\frac{birr}{yr}\right) \quad (4.2.23)$$

$$\text{ACS} = 532408.3\left(\frac{l}{yr}\right) * 17\text{birr/l} = 90{,}507.15\text{birr/yr} = \$3232.39$$

g) Investment cost = [cost of air blower motor ($500) = 14000+labor cost (2600birr) =16,600birr]

h) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{birr}{yr})} \quad (4.2.24)$$

$$P_b = \frac{16{,}600\text{birr}}{90507.15\text{birr/yr}} = 0.18\text{yr}$$

**Improvement plan 2: Thermo Boiler Flue Gas Waste Heat Recovery**

The improvement plan is cool water preheating to use at dyeing machine through thermo oil boiler flue gas waste heat recovery( economizer).That is the flue gas waste heat recovered is used to preheat the cool water coming from RO tank used for dyeing machine. For every 22.8℃ rises in flue gas temperature the thermal efficiency of thermo boiler decrease by 1%. The standard and goal of flue gas temperature of thermo oil boiler is 190℃ and 140℃ respectively

Thermo boilers are not used to generate steam or hot water but they use to supply high temperature thermo oil to dryer and stenter. The exhausted heat can be used to heat water by recovering.

The input (entrance) temperature of thermo boiler 221℃ is the heat entering to thermo boiler formed due to combustion process (combustion air+ fuel) and the output temperature (temperature of the hot circulating thermal oil) of thermo boiler 230℃ is formed when the input 221℃ heat combines with texathemic46 thermo oil and this high temperature thermo oil circulates through dryer and stenter to dry the wet fabrics through the energy produced by oil circulation pump motor.

Increasing energy costs and environmental bother gives strong motivation for applying more and newer energy improving methods and technologies for waste heat recovery systems.

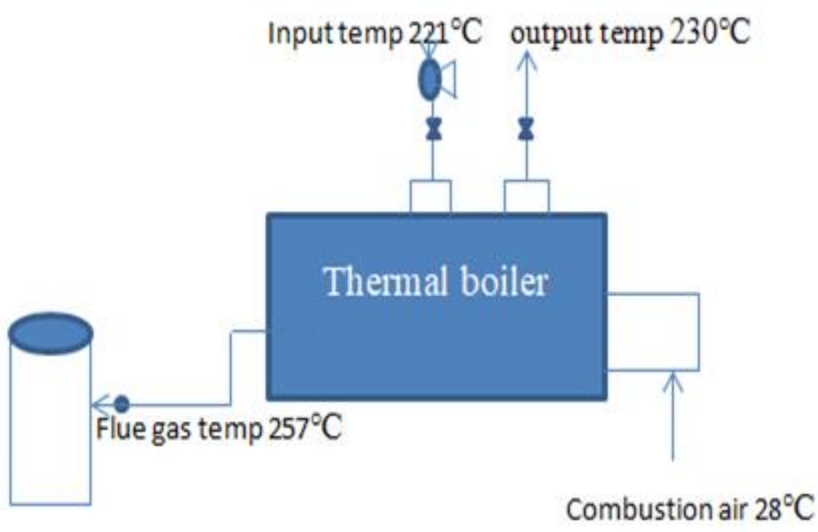


Figure 4-2: Existing system of thermo boiler

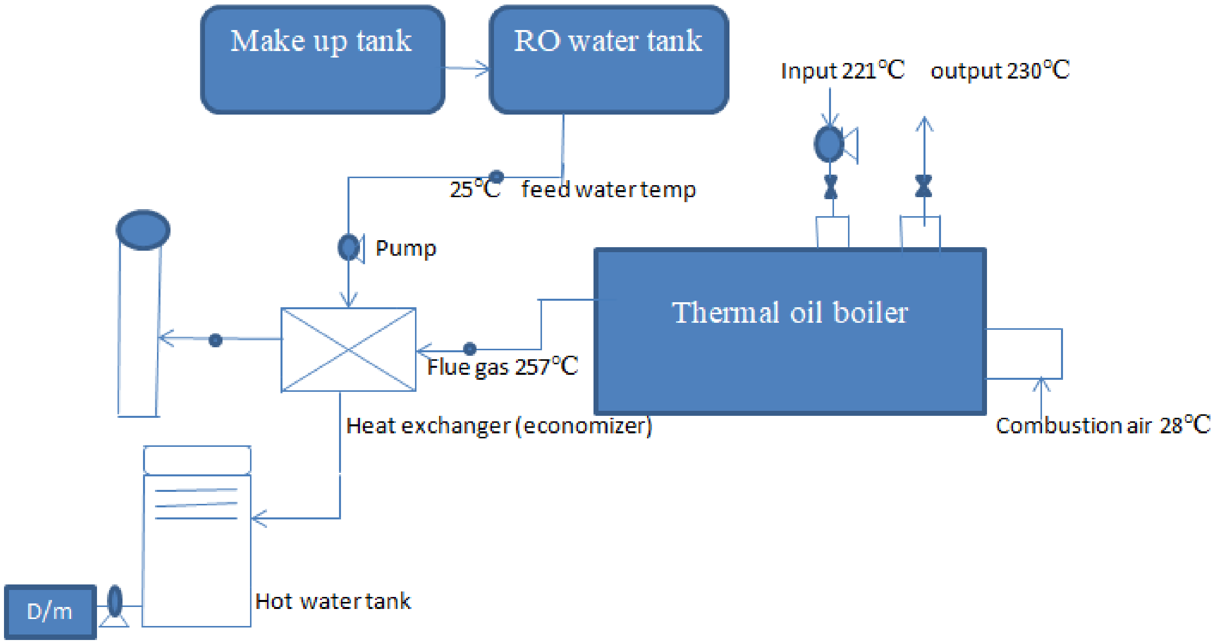


Figure 4-3: Improved thermo oil boiler flue gas waste heat recovery system

Here the waste heat recovered is used for heating water used for dyeing machine. That is the heat exchanger (economizer) exchanges heat of flue gas and RO water tank and the hot water flows to hot water tank used in dyeing machine. This hot water is used when the dyeing machines need hot water in short time that don't give time until the water heated by the boiler because the water heated by this have enough temperature needed by dyeing due to high temperature of thermo oil.

**Reverse osmosis (RO):-** is a water ceremonially clean application which uses a semipermeable membrane to avoid ions, and other insolvent materials from water.

**Make up water: -** is the source water which fills the evaporated or leaked water from the boiler or it is first drawn from its source.

Advantages of waste heat recovery systems are:

- Fuel saving, transform the energy
- reduce greenhouse gas emission
- Generate electricity, reduce capital investment cost
- Sell heat and electricity, increase production

■ Calculation standards [18][21]

Table 4-8: Variables used in calculating the expect result of thermo boiler

| | | | |
|---|---|---|---|
| $m_1$ | = | current air ratio | 1.391 |
| $m_2$ | = | air ratio after control(standard air ratio) | 1.2 |
| $G_0$ | = | Theoretical flue gas flow rate | 11.84($Nm^3$/kg) |
| $A_O$ | = | theoretical combustion air flow rate | 11.02($Nm^3$/kg) |
| $C_g$ | = | Flue gas average specific heat | 0.33(kcal/$Nm^3$°C) |
| $Q_i$ | = | low heat value | 10,000(kcal/kg) |
| $tg_1$ | = | Flue gas temperature before improve | 257(°C) |
| $tg_2$ | = | Flue gas temperature after improve = goal[from standard] | 140(°C) |
| Fuel consumption | = | 357,312 l/yr | |
| Fuel unit price | = | birr/l | |

**Expected results**

a) Heat recovery (Q)

$$Q = \{G_O + (m_2 - 1) * A_O\} * C_g * \left(t_{g1} - t_{g2}\right) \quad (4.2.25)$$

$$Q = \{11.84 + (1.2 - 1) * 11.02\} * 0.33 * (257 - 140) = 542\text{kcal/kg}$$

b) Reduction rate (E)

$$E = \left\{\frac{\text{Heat recovery}\left(\frac{\text{kcal}}{\text{kg}}\right)}{\text{low heat value}\left(\frac{\text{kcal}}{\text{kg}}\right)}\right\} * 100\% \quad (4.2.26)$$

$$E = \frac{Q}{Q_i} * 100\% = \frac{542}{10{,}000} * 100\% = 5.4\% = 0.054$$

c) Annual fuel savings/reduction

$$\text{AFS} = \text{annual fuel consumption}\left(\frac{\text{l}}{\text{yr}}\right) * \text{reduction rate} \quad (4.2.27)$$

$$\text{AFS} = 357{,}312\text{l/yr} * 0.054\% = 19{,}295\ \text{l/yr} = 19.295\text{kl} * 0.901\text{toe/kl} = 17.38\text{toe/yr}$$

d) Total energy reduction rate

$$\text{TERR} = \frac{\text{annual fuel saving}\left(\frac{\text{l}}{\text{yr}}\right)}{\text{annual energy consumption}\left(\frac{\text{l}}{\text{yr}}\right)} * 100\% \quad (4.2.28)$$

$$\mathrm{TERR} = \frac{19295\left(\frac{\mathrm{l}}{\mathrm{yr}}\right)}{357312(\frac{\mathrm{l}}{\mathrm{yr}})} * 100\% = 5.4\%$$

e) Greenhouse gas reduction

$$\mathrm{GGR} = \text{annual fuel saving}\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right) * \text{light oil C emission coeficient}\left(\frac{\mathrm{tc}}{\mathrm{toe}}\right) \quad (4.2.29)$$

$$\mathrm{GGR} = 17.38\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right) * 0.846\left(\frac{\mathrm{tc}}{\mathrm{toe}}\right) = 14.7\mathrm{tc/yr}$$

f) Annual cost savings

$$\mathrm{ACS} = \text{annual fuel saving}\left(\frac{\mathrm{l}}{\mathrm{yr}}\right) * \text{fuel unit price}\left(\frac{\mathrm{birr}}{\mathrm{l}}\right) \quad (4.2.30)$$

$$\mathrm{ACS} = 19295\left(\frac{\mathrm{l}}{\mathrm{yr}}\right) * 17\mathrm{birr/l} = 328{,}015\mathrm{birr/yr}$$

g) Investment cost = [cost of economizer $15000 = 420,000birr +labor cost =$600= 16,800 birr, total cost = 436,800birr]]

h) Payback period of investment (Pb)

$$P_b = \frac{\text{investmentcost(birr)}}{\text{annual cost saving}(\frac{\mathrm{birr}}{\mathrm{yr}})} \quad (4.2.31)$$

$$P_b = \frac{436{,}800\mathrm{birr}}{328{,}015(\frac{\mathrm{birr}}{\mathrm{yr}})} = 1.3\mathrm{yr}$$

## 4.3. Heat Transport Facility Insulation Method

**Problem**

The problem is radiation and convective heat loss occurs in steam head valve and thermo-oil valve due to loss of their insulation as shown at the thermal image of figure 4-4.

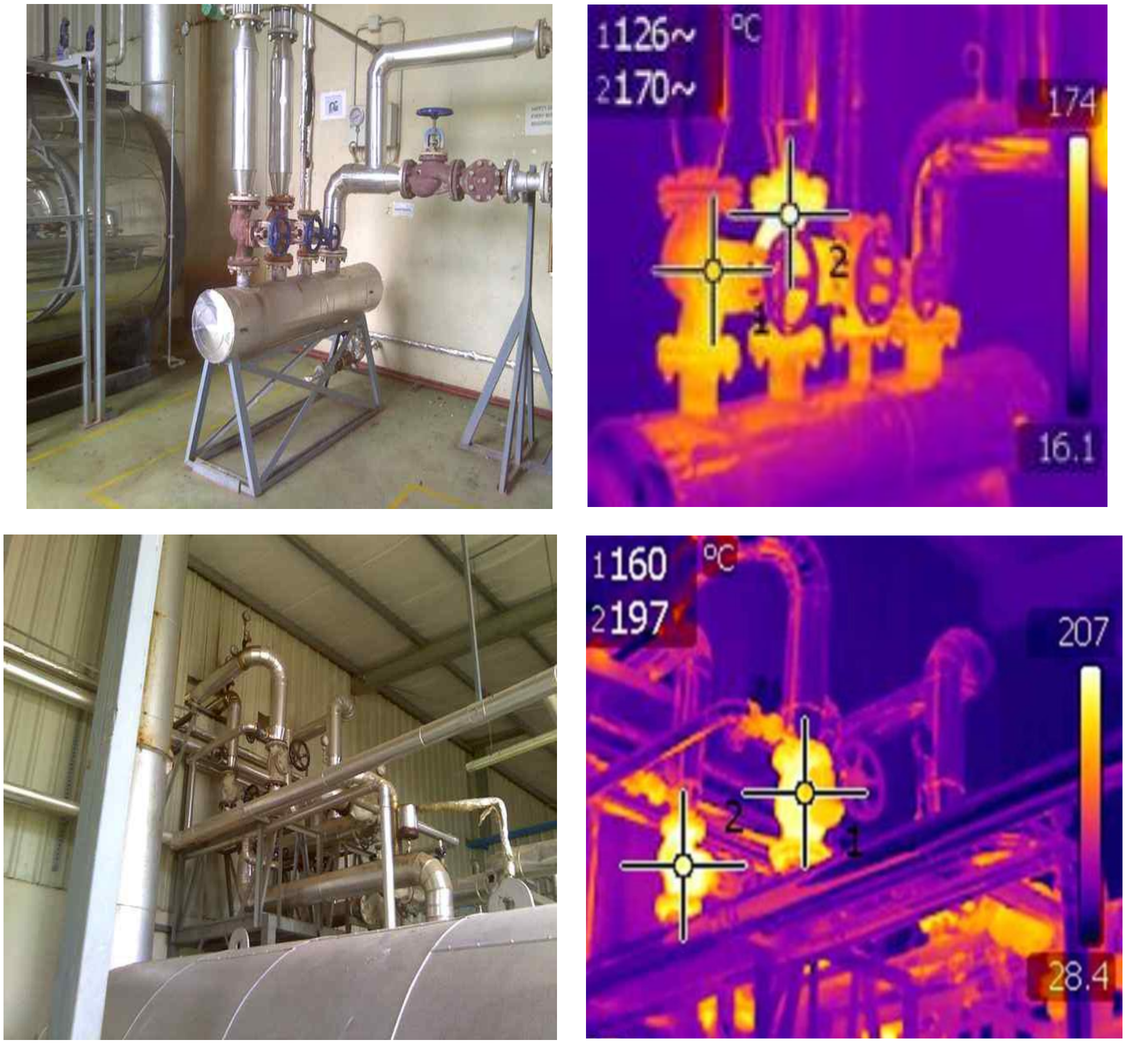


Figure 4-4: Actual and thermal image of steam head valve and thermo oil valve

**Improvement Plan**

The improvement plan is radiation and convection heat loss reduction in heat transport facilities through steam header valve and thermo oil pipe line insulation.

■ Calculation standards [22][23] we take the steam header valve or the first one for calculation.

◦ Applicable area: A= 5m$^2$ [insulation loss area of steam head valve]

◦ Average surface temperature of steam head valves: (126+170)/2=148(℃)

Radiative heat transfer coefficient (hr) $=E*(ts/100)^4 - (tr/100)^{4*}(\varepsilon/ts-tr)$

Radiative heat transfer coefficient before insulation (hr1) $=E*(ts_1/100)^4-(tr_1/100)^{4*}(\varepsilon/ts_1-tr_1)$

where E is the emissivity coefficient of surface material of the boiler (0.88) and ε is the total radiative coefficient (0.8)

Radiative heat transfer coefficient after insulation ($hr_2$) =E*($ts_2$/100)$^4$-($tr_2$/100)$^{4*}$(ε/$ts_2$-$tr_2$)

Convective heat transfer coefficient (hc) =k*(ts-tr), where **k** is the multiplying factor which equals to 2.8 when the boiler is located in horizontal up surface from ground.

Convective heat transfer coefficient before insulation ($hc_1$**)** = k*($ts_1$-$tr_1$)

Convective heat transfer coefficient after insulation ($hc_2$**)** =k*($ts_2$-$tr_2$)

Heat transfer coefficient **(**h) = hr+hc, where $h_1$=$hr_1$+$hc_1$ and $h_2$=$hr_2$+$hc_2$

Heat loss reduction=A*{$h_1$*($ts_1$-$tr_1$)-$h_2$ ($ts_2$-$tr_2$)} =A* ($Q_1$-$Q_2$)

Table 4-9: Variables used to calculate the expected effect steam header valve and thermo oil valve insulation loss (measured and calculated values)

| Section | | | Data |
|---|---|---|---|
| A | = | insulation application area($m^2$) | 5 |
| $hr_1$ | = | radiative heat transfer coefficient before insulation(kcal/$m^2$·h·°C) | 7.550 |
| $hr_2$ | = | radiative heat transfer coefficient after insulation(kcal/$m^2$·h·°C) | 4.987 |
| $hc_1$ | = | convective heat transfer coefficient before insulation(kcal/$m^2$·h·°C) | 9.267 |
| $hc_2$ | = | convective heat transfer coefficient after insulation(kcal/$m^2$·h·°C | 6.660 |
| $h_1$ | = | heat transfer coefficient before insulation(kcal/$m^2$·h·°C) | 16.817 |
| $h_2$ | = | heat transfer coefficient after insulation(kcal/$m^2$·h·°C) | 11.647 |
| $ts_1$ | = | surface temperature before insulation(°C) | 148 |
| $ts_2$ | = | surface temperature after insulation(°C) | 60 |
| $tr_1$ | = | ambient temperature before insulation(°C) | 28 |
| $tr_2$ | = | ambient temperature after insulation(°C) | 28 |
| K | = | 2.2(vertical surface), 2.8(horizontal up surface),(horizon surface), 1.5(horizontal down-surface) | 2.8 |
| ε | = | total radiative coefficient | 0.8 |
| $Q_1$ | = | radiative heat before insulation(kcal/$m^2$·°C) | 2018 |
| $Q_2$ | = | radiative heat after insulation(kcal/$m^2$·°C) | 372.7 |
| Q | = | reduction heat(kcal/h) | 1645.3 |

**Expected Results**

a) Heat loss reduction/saving/recovery (Q)

$$Q = (Q_1 - Q_2) * \text{area} \qquad (4.3.1)$$

$$Q_1 = h_1(ts_1 - tr_1) = 16.817 * (148 - 28) = 2018\text{kcal}/m^2\text{°C}$$

$$Q_2 = h_2(ts_2 - tr_2) = 11.647(60 - 28) = 372.7\text{kcal}/m^2\text{°C}$$

$$Q_1 - Q_2 = 2018 - 372.7 = 1645.3\text{kcal/hr}$$

$$\text{Q} = 1645.3 * 8760\text{hr/yr} = 14{,}412{,}828\text{kcal/yr} * 5m^2 = 72{,}064{,}140\text{kcal/yr}$$

b) Annual fuel saving/reduction

$$\text{AFS} = \frac{\text{heat recovery} * \text{specific gravity}}{\text{light oil low heat value}} \tag{4.3.2}$$

$$\text{AFS} = \frac{\left\{72064140\left(\frac{\text{kcal}}{\text{yr}}\right) * 0.83(\frac{\text{kg}}{\text{l}})\right\}}{10{,}000\text{kcal/kg}} = 8682.4\ \text{l/yr}$$

$$\text{AFS} = 8.6824\left(\frac{\text{kl}}{\text{yr}}\right) * 0.901\left(\frac{\text{toe}}{\text{yr}}\right) = 7.823\text{toe/yr[light oil conversion standard]}$$

c) Total energy reduction rate

$$\text{TERR} = \frac{\text{annual fuel saving}\left(\frac{\text{toe}}{\text{yr}}\right)}{\text{annual energy consumption}(\frac{\text{toe}}{\text{yr}})} * 100\% \tag{4.3.3}$$

$$\text{TERR} = \frac{7.823\left(\frac{\text{toe}}{\text{yr}}\right)}{3473.92(\frac{\text{toe}}{\text{yr}})} * 100\% = 0.225\%$$

d) Greenhouse gas reduction

$$\text{GGR} = \text{annual fuel reduction} * \text{light oil Cemission coefficient}\left(\frac{\text{tC}}{\text{toe}}\right) \tag{4.3.4}$$

$$\text{GGR} = 7.823\left(\frac{\text{toe}}{\text{yr}}\right) * 0.846\left(\frac{\text{tC}}{\text{toe}}\right) = 6.62(\frac{\text{tC}}{\text{yr}})$$

e) Annual cost savings

$$\text{ACS} = \text{annual fuel reduction}\left(\frac{\text{l}}{\text{yr}}\right) * \text{fuel unit price}\left(\frac{\text{birr}}{\text{l}}\right) \tag{4.3.5}$$

$$\text{ACS} = 8682.4\left(\frac{\text{l}}{\text{yr}}\right) * 17\left(\frac{\text{birr}}{\text{l}}\right) = 147{,}600\text{birr/yr}$$

f) Investment cost = [25,000Birr = insulation cost +labor cost]

g) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{\text{birr}}{\text{yr}})} \tag{4.3.6}$$

$$P_b = \frac{25{,}000\text{birr}}{147600(\frac{\text{birr}}{\text{yr}})} = 0.17\text{yr}$$

## 4.4. Dyeing Machine Waste Water Heat Recovery System

### Present condition and Problem

There are a total of five dyeing machines in the factory those are 2-1tube, 2-3tube and 1-5 tube.

**Problem:** A large quantity of hot water is wasted out in the factory due to absence of waste water heat recovery system and it affects the people of community.

### Improvement Plan

The improvement plan is RO water preheating by using waste water heat through implementation of waste water heat recovery system (heat exchanger) used in dyeing machine. A heat exchanger is a machine that passes heat from one fluid (a liquid or a gas) to a second fluid (another liquid or gas) without the two fluids mixing together or come into direct contact. The type of heat exchanger used to exchange heat between fluids is recuperator and regenerator but recuperator is better because the hot and cold water are flowing in opposite direction at the same time in two different channels to exchange their heat but in regenerator the two fluids (hot and cold) flow through the same channel in opposite direction at different time then the heat transfer is decreased. Implementation of WHRS is like below fig 4-5.

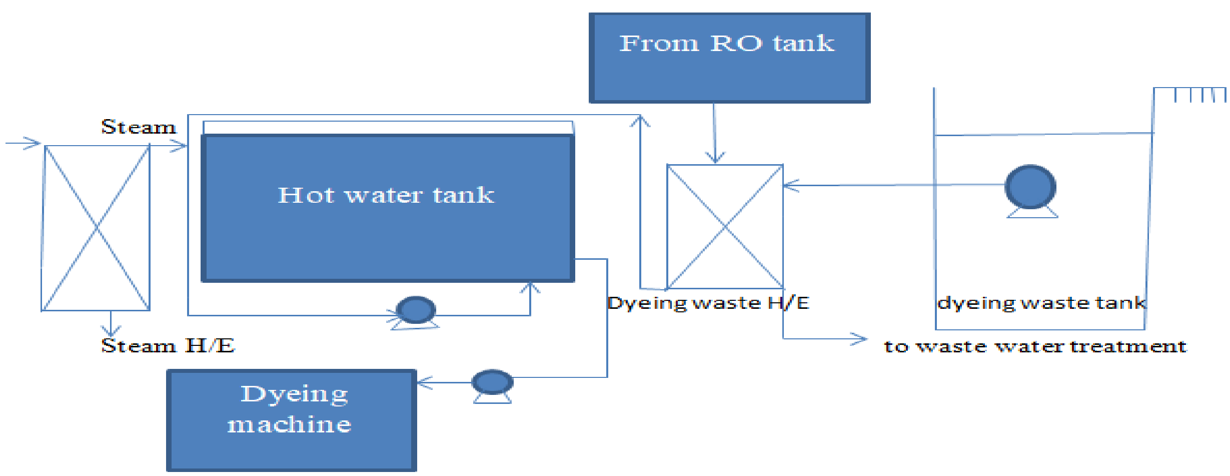


Figure 4-5: Improved dyeing machine waste water heat recovery

The waste water and RO tank water are flow with their own pipe they don't mix together they only exchange their heat through heat exchanger. The heated water in the hot water tank is kept in that tank that is it is used when the factory needs hot water in short time that cannot give time until water heated by boiler.

**Expected Results**

Calculation standards [18][37]

Table 4-10: Dyeing machine status

| Section | Unit | 1 tube | 3 tube | 5 tube |
|---|---|---|---|---|
| Capacity | kg/batch | 150 | 300 | 750 |
| Numbers | - | 2 | 2 | 1 |
| Dyeing Water Amount per Batch | l/batch | 900 | 1800 | 4200 |
| Dyeing water ratio | - | 1:6 | 1:6 | 1:6 |

Dyeing machine waste water flow rate per day = dyeing water amount per batch*dyeing batch per day

Dyeing batch per day = 2.5(batch/d)[from factory]

1 tube dyeing machine waste water flow rate per day =900(l/batch) * 2.5(batch/d) = 2,250(l/d)

3 tube dyeing machine waste water flow rate per day =1,800(l/batch) * 2.5(batch/d) = 4,500(l/d)

5 tube dyeing machine waste water flow rate per day =4,200(l/batch)*2.5(batch/d) = 10,500(l/d)

Total dyeing machine waste water flow rate =2250+4500+10500=17250(l/d)

Waste water temperature: 49(°C)[from readings]

Dyeing water temperature: 23(°C) =RO make up temperature

Light oil low heat value: 10,000(kcal/kg)

Light oil specific gravity: 0.83(kg/l)

Annual operating days: 350(d/yr)

a) Heat recovery (Q)

$$Q = \text{total waste water flow rate}\left(\frac{\text{l}}{\text{d}}\right) * \text{annual operating days}\left(\frac{\text{d}}{\text{yr}}\right) * (\text{waste water temp} - \text{dyeing water inlet temp} \qquad (4.4.1)$$

$$Q = 17250\left(\frac{l}{d}\right) * 350\left(\frac{d}{yr}\right)(49℃ - 23℃) = 156{,}975{,}000\ \text{kcal/yr}$$

b) Annual fuel saving(reduction)

$$AFS = \frac{\left\{\text{heat recovery}\left(\frac{\text{kcal}}{\text{yr}}\right) * \text{specific gravity}\right\}}{\text{light oil low heat value}} \tag{4.4.2}$$

$$AFS = \frac{156{,}975000 * 0.83}{10{,}000} = 18{,}913\ \text{l/yr}$$

$$AFS = 18.913\text{kl/yr} * 0.901\text{toe/kl} = 17.04\ \text{toe/yr}[\text{Light oil conversion standard}]$$

c) Total energy reduction rate

$$TERR = \frac{\text{annual fuel reduction}\left(\frac{\text{toe}}{\text{yr}}\right)}{\text{annual energy consumption}(\frac{\text{toe}}{\text{yr}})} * 100\% \tag{4.4.3}$$

$$TERR = \frac{17.04\left(\frac{\text{toe}}{\text{yr}}\right)}{3473.92(\frac{\text{toe}}{\text{yr}})} * 100\% = 0.49\%$$

d) Greenhouse gas reduction

$$GGR = \text{annual fuel reduction}\left(\frac{\text{toe}}{\text{yr}}\right) * \text{light oil C emission coefficient}\left(\frac{\text{tC}}{\text{toe}}\right) \tag{4.4.4}$$

$$GGR = 17.04\left(\frac{\text{toe}}{\text{yr}}\right) * 0.846\left(\frac{\text{tC}}{\text{toe}}\right) = 14.42(\frac{\text{tC}}{\text{yr}})$$

e) Annual cost savings

$$ACS = \text{annual fuel saving}\left(\frac{l}{\text{yr}}\right) * \text{fuel unit price}\left(\frac{\text{birr}}{l}\right) \tag{4.4.5}$$

$$ACS = 18{,}913\left(\frac{l}{\text{yr}}\right) * 17\left(\frac{\text{birr}}{l}\right) = 321{,}521\ \text{birr/yr}$$

f) Investment cost = [cost of heat exchanger $500 and expect total labor costs of $760 =15,000+22,800 = 37800birr]

g) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{\text{birr}}{\text{yr}})} \tag{4.4.6}$$

$$P_b = \frac{37{,}800\text{birr}}{321{,}521(\frac{\text{birr}}{\text{yr}})} = 0.12\text{yr}$$

## 4.5. Dyeing Machine Adiabatic Paint Coating System

**Problem**

The problem of dyeing machine is radiation and convection heat loss occur due to loss of insulation coating as shown in the figure below of dyeing machine thermal image of Maa Garment and Textile Factory.

Heat loss occurs by radiation and convection from high temperature materials surface containing much heat value at inside. Heat loss rate caused by radiation increase in proportion to four square of absolute temperature according to rising surface temperature.

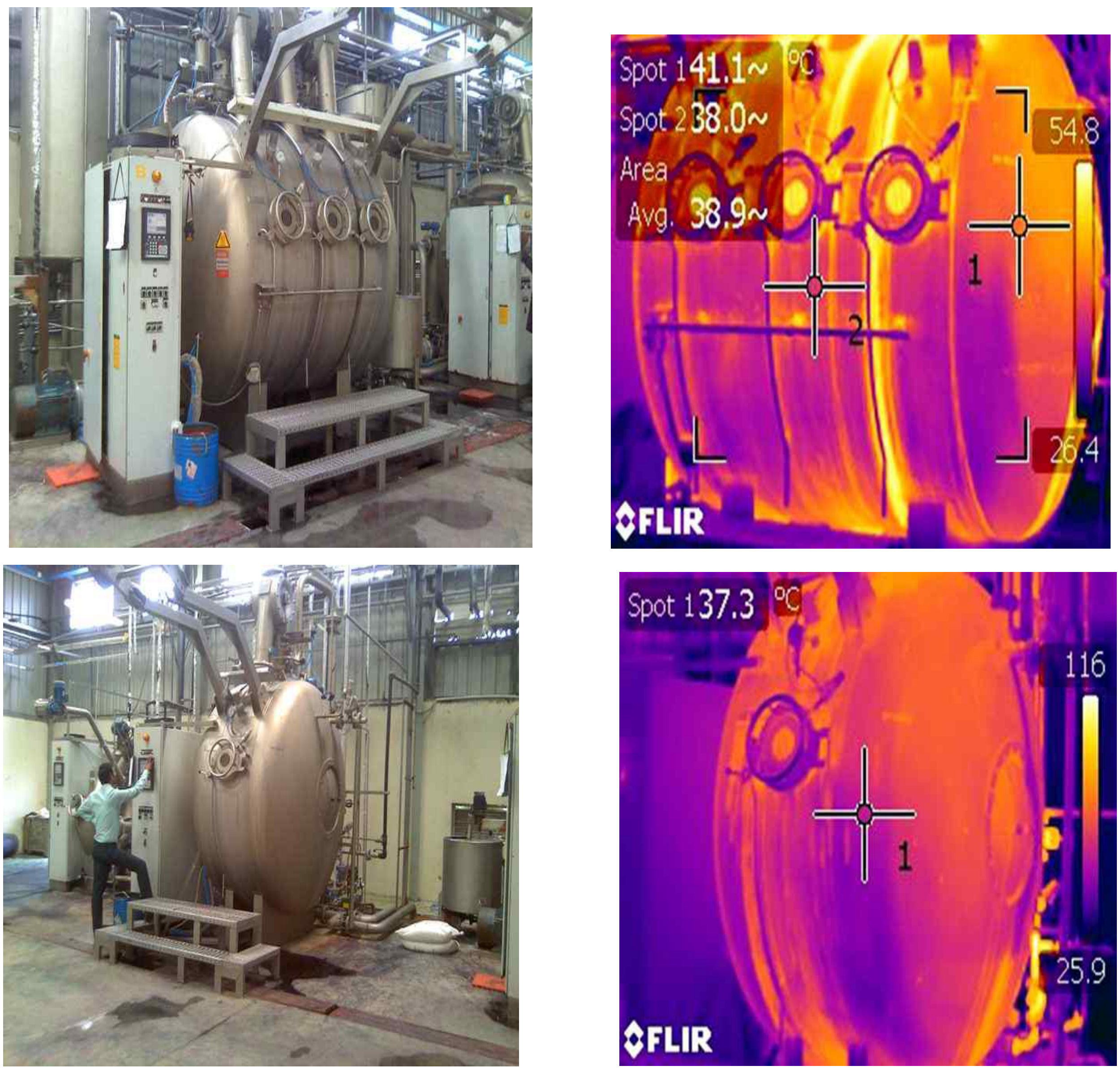


Figure 4-6: Dyeing machine actual and thermal image

**Improvement Plan**

The improvement plan is radiation and convection heat loss reduction by high functional adiabatic paint coating at no insulation part.

■ Calculation standards: [22] [29]

Applicable area: $95m^2$[average insulation area of the three spot dyeing machine]

Average surface temperature of the three spot dyeing machine: 90℃

Radiative heat transfer coefficient (hr) = $E*(ts/100)^4-(tr/100)^4*(\varepsilon/ts-tr)$, where E is the emissivity coefficient of surface material of the boiler (0.88), and ε is the total radiative coefficient (0.8).

Convective heat transfer coefficient (hc) = k*(ts-tr), where **k** is the multiplying factor which is equals to 2.8 when the boiler is located in horizontal up surface to the ground.

Heat transfer coefficient (h) =hr+hc, where $h_1=hc_1+hr$ and $h_2 = hc_2+hr_2$

Convective heat transfer coefficient before insulation ($hc_1$) = $k*(ts_1-tr_1)$

Convective heat transfer coefficient after insulation ($hc_2$) = $k*(ts_2-tr_2)$

Radiation heat transfer coefficient before insulation ($hr_1$) = $E*(ts_1/100)^4- (tr_1/100)^4 *(\varepsilon/ts_1-tr_1)$

Radiation heat transfer coefficient after insulation ($hr_2$) = $E*(ts_2/100)^4-(tr_2/100)^4 *(\varepsilon/ts_2-tr_2)$

Heat loss reduction=$A*\{h_1*(ts_1-tr_1)-h_2 (ts_2-tr_2)\}$ =A $(Q_1-Q_2)$

Table 4-11: Variables used in calculating the effect of loss in paint coating in dyeing machine

| Section | | | Data |
|---|---|---|---|
| A | = | insulation application area($m^2$) | 95 |
| $hr_1$ | = | radiative heat transfer coefficient before insulation(kcal/m²·h·°C) | 5.764 |
| $hr_2$ | = | radiative heat transfer coefficient after insulation(kcal/m²·h·°C) | 4.520 |
| $hc_1$ | = | convective heat transfer coefficient before insulation(kcal/m²·h·°C) | 7.857 |
| $hc_2$ | = | convective heat transfer coefficient after insulation(kcal/m²·h·°C | 5.211 |
| $h_1$ | = | heat transfer coefficient before insulation(kcal/m²·h·°C) | 13.621 |
| $h_2$ | = | heat transfer coefficient after insulation(kcal/m²·h·°C) | 9.732 |
| $ts_1$ | = | surface temperature before insulation(°C) | 90 |
| $ts_2$ | = | surface temperature after insulation(°C) | 40 |
| $tr_1$ | = | ambient temperature before insulation(°C) | 28 |
| $tr_2$ | = | ambient temperature after insulation(°C) | 28 |
| K | = | 2.2(vertical surface), 2.8(horizontal up-surface), 1.5(horizontal down-surface) | 2.8 |
| ε | = | total radiative coefficient | 0.8 |
| $Q_1$ | = | radiative heat before insulation(kcal/m²·°C) | 844.5 |
| $Q_2$ | = | radiative heat after insulation(kcal/m²·°C) | 116.8 |
| Q | = | reduction heat(kcal/h) | 727.7 |

- **Expected Results**

a) Heat loss reduction/saving/recovery (Q)

$$\text{Q} = (Q_1 - Q_2) * \text{area} \tag{4.5.1}$$

where $Q_1 = h_1(ts_1 - tr_1) = 13.621(90 - 28) = 844.5\text{kcal}/m^2 \cdot {}^\circ\text{C})$

$\text{Q2} = h_2(ts_2 - tr_2) = 9.732(40 - 28) = 116.8\text{kcal}/m^2 \cdot {}^\circ\text{C})$

$Q_1 - Q_2 = 844.5 - 116.8 = 727.7\text{kcal/hr}$

$\text{Q} = 727.7\text{kcal/h} * 8760\text{hr/yr} * 95m^2 = 605{,}591{,}940\text{kcal/yr}$

b) Annual fuel saving/reduction

$$\text{AFS} = \frac{\left\{\text{heat recovery}(\frac{\text{kcal}}{\text{yr}}) * \text{specific gravity}(\frac{\text{kg}}{\text{l}})\right\}}{\text{light oil low heat value}(\frac{\text{kcal}}{\text{kg}})} \tag{4.5.2}$$

$$\text{AFS} = \frac{\left\{605{,}591{,}940\left(\frac{\text{kca}}{\text{yr}}\right) * 0.83\left(\frac{\text{kg}}{\text{l}}\right)\right\}}{10{,}000(\frac{\text{kcal}}{\text{kg}})} = 50{,}264.13(\frac{\text{l}}{\text{yr}})$$

$$\text{AFS} = 50.264\left(\frac{\text{kl}}{\text{yr}}\right) * 0.901\left(\frac{\text{toe}}{\text{kl}}\right) = 45.29(\frac{\text{toe}}{\text{yr}})[\text{light oil conversion standard}]$$

c) Total energy reduction rate

$$\text{TERR} = \frac{\text{annual fuel reduction}\left(\frac{\text{toe}}{\text{yr}}\right)}{\text{annual energy consumption}(\frac{\text{toe}}{\text{yr}})} * 100\% \tag{4.5.3}$$

$$\text{TERR} = \frac{45.29\left(\frac{\text{toe}}{\text{yr}}\right)}{3473.92(\frac{\text{toe}}{\text{yr}})} * 100 = 1.3\%$$

d) Greenhouse gas reduction

$$\text{GGR} = \text{annual fuel reduction}\left(\frac{\text{toe}}{\text{yr}}\right) * \text{light oil C emission coeffieient}\left(\frac{\text{tC}}{\text{toe}}\right) \tag{4.5.4}$$

$$\text{GGR} = 45.29\left(\frac{\text{toe}}{\text{yr}}\right) * 0.846\left(\frac{\text{tC}}{\text{toe}}\right) = 38.315(\frac{\text{tC}}{\text{yr}})$$

e) Annual cost savings

$$\text{ACS} = \text{annual fuel saving}\left(\frac{\text{l}}{\text{yr}}\right) * \text{fuel unit price}\left(\frac{\text{birr}}{\text{l}}\right) \tag{4.5.5}$$

$$\text{ACS} = 50{,}264.13\left(\frac{\text{l}}{\text{yr}}\right) * 17\left(\frac{\text{birr}}{\text{l}}\right) = 854{,}490.21\text{birr/yr}$$

f) Investment cost = [158,300Birr = cost of insulation coating + labor cost]

g) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{\text{birr}}{\text{yr}})} \tag{4.5.6}$$

$$P_b = \frac{158300\text{birr}}{854{,}490.2(\frac{\text{birr}}{\text{yr}})} = 0.185\text{yr}$$

## 4.6. Air Compressor Intake Temperature Improvement System

**Problem**

The electric consumption of air compressor is high due to entering of hot air to the air compressor again. Because if the air intake to air compressor is hot then the power needed to cool or remove this hot air is high that is as shown below the temperature of the room is higher than the ambient temperature in all departments then the power needed by the air compressor to cool or remove this hot air to become the same as ambient is high. Ambient temperature, indoor temperature, intake temperature status are presented below in Table 4-12.

Table 4-12: Air compressor temperature status

| Section | $T_1$= room temperature(℃) | $T_1$($^o$k) | $T_2$ = ambient temperature(℃) | $T_2$($^o$k) |
|---|---|---|---|---|
| Spinning and knitting department | 33 | 306 | 28 | 301 |
| Dyeing department | 30 | 303 | 28 | 301 |

**Improvement Plan**

The improvement plan is intake room hot air down or totally removes through control of indoor temperature by installing exhausted air duct at air compressor and use maximum outdoor temperature. As intake hot air decrease the electric power consumption also decrease because to cooling or remove this room hot air the power required is higher. The reason is the air in the room is hotter than outdoor temperature as shown in the above table therefore the energy required to cool this hot air is very high.

Here the installed exhausted air duct removes the hot air from the rooms then the room temperature becomes the same with ambient temperature.

Ducts are tubes or channels used in heating, ventilation and air conditioning to conduct and avoid air the required airflows include for example, supply air**;** return air, and flue gases. Exhausted air ducts are ducts used to avoid flue gas or hot air from the room to the atmosphere. Ducts usually also take ventilation air as part of the supply air.


Figure 4-7: Installation of exhausted air duct at air compressor

Air compressor power changes according to temperature change that is as intake hot air temperature decrease air compressor power also decrease that is in case of every 3℃ intake temperature down, Electric consumption of air compressor reduce 1(%) like below figure 4-8.

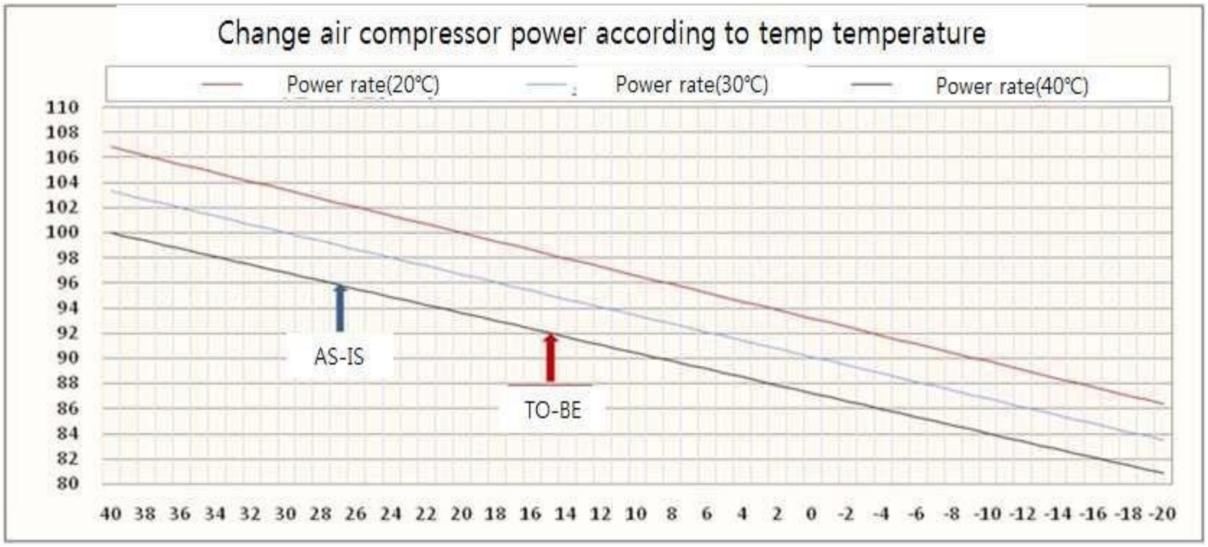


Figure 4-8: Concerning chart of intake temperature vs electric consumption

**Expected results**

Calculation standards [18][37]

$$E = \left[1 - \frac{T_2}{T_1}\right] * 100\% \qquad (4.7.1)$$

Where E: electric reduction rate (%)

$T1$: intake air temperature before improve (°K) = room temperature

$T2$: intake air temperature after improve (°K) that is after design exhaust air duct T2 equals to the ambient temperature that is the exhausted air duct will make the air intake to air compressor equals with ambient temperature. Here the intake air temperature is decreased after installing exhausted air duct because it removes the hot air entering again to the room.

- For spinning and knitting:

$$E = \left[1 - \frac{T_2}{T_1}\right] * 100\% = \left[1 - \frac{301}{306}\right] * 100\% = 1.6\% \qquad (4.7.1.1)$$

- For dyeing:

$$E = \left[1 - \frac{T_2}{T_1}\right] * 100\% = \left[1 - \frac{301}{303}\right] * 100\% = 0.7\% \qquad (4.7.1.2)$$

$$\text{Electric reduction(kw)} = \frac{\{\text{electric consumption(kw)} * \text{reduction rate(\%)}\}}{100\%} \qquad (4.7.2)$$

Electric consumption (kW) = sum of power consumed by the operating air compressors

- For spinning and knitting:
- Electric consumption = 99.12kw+16.15kw+4.46kw = 119.63kw

$$\text{Electric reduction} = \frac{\{119.63\text{kw} * 1.6\%\}}{100\%} = 1.91\text{kw} \quad (4.7.2.1)$$

- For dyeing:
- electric consumption = power air compressor1= 9.7kw because it is only in operation

$$\text{Electric reduction} = \frac{\{9.74\text{kw} * 0.7\%\}}{100\%} = 0.07\text{kw} \quad (4.7.2.2)$$

- $\text{total electric reduction} = 0.07\text{kw} + 1.91\text{kw} = 1.98\text{kw}$

a) Annual power savings(reduction)

$$\text{APS} = \text{electric reduction(kw)} * \text{annual operating hours}\left(\frac{\text{hr}}{\text{yr}}\right) \quad (4.7.3)$$

$$\text{APS} = 1.98\text{kw} * 8400\left(\frac{\text{hr}}{\text{yr}}\right) = 16{,}632\left(\frac{\text{kwh}}{\text{yr}}\right)$$

$$\text{APS} = 16.632\left(\frac{\text{Mwh}}{\text{yr}}\right) * 0.230\left(\frac{\text{toe}}{\text{Mwh}}\right) = 3.83\left(\frac{\text{toe}}{\text{yr}}\right)$$

b) Total energy reduction rate

$$\text{TERR} = \frac{\text{annual electric saving}\left(\frac{\text{toe}}{\text{yr}}\right)}{\text{annual energy consumption}\left(\frac{\text{toe}}{\text{yr}}\right)} * 100\% \quad (4.7.4)$$

$$\text{TERR} = \frac{3.83\left(\frac{\text{toe}}{\text{yr}}\right)}{3473.92\left(\frac{\text{toe}}{\text{yr}}\right)} * 100\% = 0.11\%$$

c) Greenhouse gas reduction

$$\text{GGR} = \text{annual electric saving} * \text{C emission coefficient of electricity} \quad (4.7.5)$$

$$\text{GGR} = 16.632\left(\frac{\text{Mwh}}{\text{yr}}\right) * 0.1283\left(\frac{\text{tC}}{\text{Mwh}}\right) = 2.134\ \text{tC/yr}$$

d) Annual cost savings

$$\text{ACS} = \text{annual electric saving}\left(\frac{\text{kwh}}{\text{yr}}\right) * \text{electric unit price}\left(\frac{\text{birr}}{\text{kwh}}\right) \quad (4.7.6)$$

$$\text{ACS} = 16{,}632\left(\frac{\text{kwh}}{\text{yr}}\right) * 0.57787\left(\frac{\text{birr}}{\text{kwh}}\right) = 9{,}700\text{birr/yr}$$

e) Investment cost [$1000+5000birr = 33,000Birr cost of exhausted air duct + labor cost].

f) Payback period of investment

$$P_b = \frac{\text{investment cost(birr)}}{\text{annual cost saving}(\frac{\text{birr}}{\text{yr}})} \quad (4.7.7)$$

$$P_b = \frac{33{,}000\text{birr}}{9700(\frac{\text{birr}}{\text{yr}})} = 3.4yr$$

## 4.7. Lighting Facilities Replacement Method

**Lighting facilities Present condition**

Lights installed at garment process of Maa Garment and Textile Factory is mainly straight type fluorescent lamp and their installations are like below figure 4-9. The total no of lamps existing now in the factory are 640 or 320 pair each lamp consumes 40watt of power that is the total power consumed by the lamps is 25.6kw.

**Lighting installation view at garment department**

Figure 4-9: Lighting installation of garment department

**Light Lamps Problem**

The lamps existing in the industry are T12 compact fluorescent lamps which are low efficient, shorter life time and high power consuming and there are also small numbers of incandescent lamps in some offices which are less efficient and high power consuming devices than T8 fluorescent lamps.

**Lighting System Energy Efficiency Improvement Techniques**

**a. Lighting Controls**

To decrease the energy waste in factories lights must be off during non-working hours by using both automatically and manually. Some of the automatic techniques of controlling lighting system are by using occupancy sensors that turn off lights automatically when a space becomes free of any body. That is occupancy sensors are sensors that senses whether the area is occupied by a person or not and it makes the light off if no one is present in the working area and it save an energy of 10% to 20% [34]. Here in lighting control method of energy saving we can control lights by combination of manual with automatic controls to save large energy. This combination of automatic and manual technique is done by installing switches to permit occupants to control lights. We can also save energy from lighting by making the workers of that area conscious of the advantage of turning off lights in free areas. Another option of lighting control or energy saving from lighting is by using sunlight instead of electric lights.

**b. High-Intensity Fluorescent Lights (HIF lights)**

Nowadays the old and high energy consuming fluorescent lights are changed by new fluorescent lights. These new changing lights are electronic ballasts, high-efficiency fluorescent lights and high-efficacy fixtures that help to increase the light efficiency and to decrease energy waste in the working area.

The importance of the new energy efficient lightings are they use less energy, the output light is decreased by a small value in the lifetime of the lamp, rapid to start-up, higher color rendering, the lumens rating is higher in pupil, and less reflection to our eye by the light. The importance of High-intensity fluorescent lighting over the standard lighting is they saves 50% of electrical energy, has good lighting character, increase in manufacturing, and has less continuance costs.

### c. Day Lighting

Day lighting is the light we get from sun. It can be used in conjunction with man-made lighting controls to increase its lumen output during summer seasons especially in cloudy days or when the light we get from artificial lights is not sufficient. The reason we use in conjunction with lighting control is because of seasonal variation. The techniques used to increase day lighting energy includes using of light passing windows, use white colored walls. Day lighting is not used by all equipment's found in the factory it is good for equipment's which consume less energy and equipment's which get sun light easily such as in offices. Most of the time day lighting is used for the areas which are occupied by the people during daytime. Based on different researchers due to day lighting we can save energy between 30 and 70% in offices. But it varies based on the equipment's used and buildings (their color and windows) [36].

### d. Replace Magnetic Ballasts with Electronic Ballasts

Electronic ballasts are used to control the amount of electrical energy needed to start a lighting installation and keep the lighting output constant.

Some of the characteristics of electronic ballasts are they consume 12% to 30% lower energy, they trouble free and hushed distinct abilities, they used for long life without burnt , they take small time to start, and they work with different colors than magnetic ballasts [37].

### e. Replacing T12 tubes by T8 tubes

In this thesis we need to replace the existing T12 light by T8 to save energy loss. There are 640 T-12 tube florescent lamps have been found in the factory but they are not efficient that is they have low lumen output.

T-8 tube fluorescent lamps have the following characteristic some of them are:

- Less energy consumption, higher efficiency and life time, less maintenance and energy costs and save up to 30% of energy than T12 lights.
- Have small diameter that is 1 inch (2.54cm) but T12 have 1.5 inches (3.81cm)
- Have improved color characteristics compared to T12 lamps
- Have high color rendering index (75-85) but T12 have CI of 52-62, Better relative light output

- The light output of T8 lamps is equal or above the light output of T12 lamps, due to many reasons.

**Evaluation of Lighting Systems**

The luminous intensity of different lightings and the standard illumination needed in different operating area are desired to assess either the existing installation is correct or not. To understand either the existing installation is right or not, we use calculations as shown below.

Table 4-13: Luminous intensity and life time of different lamps [37]

| No. | Lamp type | Luminous Intensity(Lumens/watt) | Relative Efficiency | Lamp Life(hrs) |
|---|---|---|---|---|
| 1 | Fluorescent tube | 70-80 | 70 | 5000-5500 |
| 2 | LED Lights | 75-120 | 95 | 50000-100,000 |
| 3 | Tungsten -Halogen Lamps | 19-24 | 78 | 2000-4500 |
| 4 | Incandescent | 9-20 | 20 | 1000-2000 |
| 5 | High Pressure Hg Vapor lamps | 45-60 | 46 | 16,000-24,000 |
| 6 | Compact Fluorescent Light(CFL) | 46 | 46 | 7500-10,000 |
| 7 | High Pressure Na Lamps(HPS) | 76-130 | 100 | 25,000 |

Table 4-14: Illuminations needed in different operating station [38]

| | Working Station | Average IL Luminance required(LUX) |
|---|---|---|
| 1 | Office , guard rooms, kitchen, library, laboratory, clinic | 450-500 |
| 2 | Boilers and pump houses | 100 |
| 3 | Weaving ,fabric and general sores | 150-750 |
| 4 | Grey close inspection | 700-1000 |
| 5 | Final inspection | 700-1000 |
| 6 | Workshops | 300-750 |
| 7 | Clock rooms, Entrances, Corridors, Stairs, | 150 |
| 8 | Garment | 350-1000 |
| 9 | Spinning | 150-500 |
| 10 | Knitting | 300-750 |
| 11 | Canteens, garage | 150-250 |
| 12 | Maintenance and winding room, | 200-300 |
| 13 | Toilet | 150-300 |

**Expected Results**

Calculation standards [18][36]

Annual operating days: 350d/yr

Lamp using rate: about 40 (%) applications

Analyze number of lamps by the following the procedures below

$$TP = NL * RL \quad (4.9.1)$$

Where TP = total power, NL = number of lamp, RL = power rating of lamp

$$TLu(lumens) = ENL(watt) * intensity\left(\frac{lumens}{watt}\right) \quad (4.9.2)$$

Intensity is luminous output of each fluorescent lamp which is 80lumens/watt.

Where ENL = existing no of lamps and TLu = total lumen output of the lamp installed in the department.

$$E = \frac{TLu(lumens)}{RA} \quad (4.9.3)$$

Where, E = the illumination produced by the installed lamps

RA =Room area of each department measured in square meter. Since lighting system needs to install based on the required standards illumination (RSE) of the specific working stations, the factory should be install the lighting system according to the standard

$$ALR = \frac{RSE(Lux)}{E(Lux) * ENL} \quad (4.9.4)$$

Where ALR= The number of lamps needed to post in each department due to use of proper illumination level with the same florescent lamp rating of the existing lamp in the factory(after improve), and RSE = Required standard illumination level of each department

$$EU = ENL * \text{rating power of lamp} * OH \quad (4.9.5)$$

Where EU = the existing energy spend by the lighting system of the industry and OH = operating hour

$$ER = ALR * \text{rating power of lamp} * OH \quad (4.9.6)$$

Where ER= the required energy after improving the utilization illumination level of the factory

$$ES = EU - ER \quad (4.9.7)$$

Where ES = energy saving after changing T12 by T8 tube fluorescent lamps

Table 4-15: Comparison of T12 tube lamps and T8 tube lamps

| no | department | ENL | TP(w) | intensity | TLU(lumens) | RA(m²) | E | ALR | RSE | OH | EU | ER | ES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | RO station | 5 | 200 | 3200 | 16000 | 35 | 457 | 4 | 350 | 12 | 2400 | 1920 | 480 |
| 2 | guard | 5 | 200 | 3200 | 16000 | 30 | 533.3 | 4 | 320 | 12 | 2400 | 1920 | 480 |
| 3 | spinning | 100 | 4000 | 3200 | 320,000 | 500 | 640 | 93 | 600 | 24 | 96000 | 89280 | 6720 |
| 4 | dyeing | 70 | 2800 | 3200 | 224,000 | 500 | 448 | 62 | 400 | 24 | 67200 | 59520 | 7680 |
| 5 | knitting | 60 | 2400 | 3200 | 192000 | 500 | 348 | 52 | 300 | 24 | 57600 | 49920 | 7680 |
| 6 | Garment | 300 | 12000 | 3200 | 960,000 | 1000 | 960 | 234 | 750 | 12 | 144000 | 112320 | 31680 |
| 7 | Managers office | 10 | 400 | 3200 | 32000 | 50 | 640 | 7 | 300 | 12 | 4800 | 3360 | 1440 |
| 8 | Electrical office | 4 | 160 | 3200 | 12800 | 50 | 256 | 3 | 200 | 12 | 1920 | 1440 | 480 |
| 9 | workshops | 20 | 800 | 3200 | 64000 | 100 | 640 | 16 | 500 | 12 | 9600 | 7680 | 1920 |
| 10 | Café | 20 | 800 | 3200 | 64000 | 100 | 640 | 16 | 500 | 12 | 9600 | 7680 | 1920 |
| 11 | HRM office | 8 | 320 | 3200 | 25600 | 50 | 512 | 5 | 300 | 12 | 3840 | 2400 | 1440 |
| 12 | Janitors and toilet | 4 | 160 | 3200 | 12800 | 40 | 320 | 3 | 250 | 12 | 1920 | 1440 | 480 |
| 13 | Electrical operator | 4 | 160 | 3200 | 12800 | 40 | 320 | 3 | 250 | 24 | 3840 | 2880 | 960 |
| 14 | Mechanical operator | 4 | 160 | 3200 | 12800 | 40 | 320 | 3 | 250 | 24 | 3840 | 2880 | 960 |
| 15 | Oil pump room | 6 | 240 | 3200 | 19200 | 50 | 384 | 4 | 250 | 12 | 2880 | 1920 | 960 |
| 16 | store | 20 | 800 | 3200 | 6400 | 150 | 426 | 14 | 300 | 12 | 9600 | 6720 | 2880 |
| 17 | total | 640 | 15200 | | | | | 523 | 5820 | | 421,440 | 353,280 | 68,160 |

The number of lamps is decreased from 640 to 523 because T8 lamps are more efficient.

a) Power saving (PS) = (ENL- ALR)*LR + 0.4*ALR*LR

Ps = (640-523)*40w+0.4*523*40w=117*40w+8368=4680+8368=13048w = 13.1kw

b) Energy Saving

$$\mathrm{ES} = (\mathrm{EU} - \mathrm{ER}) + (0.4 * \mathrm{ER}) \quad (4.9.7)$$

$$\mathrm{ES} = 68.16\mathrm{kwh} + 141.3\mathrm{kwh} = 209.472\mathrm{kwh/d}$$

$$\mathrm{ES} = 209.472\mathrm{kwh/d} * 350\mathrm{d/yr} = 73315.2\mathrm{kwh/yr} = 73.31\mathrm{Mwh/yr} = 16.86\mathrm{toe/yr}$$

b) Annual cost saving

$$\mathrm{ACS} = \text{annual energy saving}\left(\frac{\mathrm{kwh}}{\mathrm{yr}}\right) * \text{electric unit price}\left(\frac{\mathrm{birr}}{\mathrm{kwh}}\right) \quad (4.9.8)$$

$$\mathrm{ACS} = 73315.2\left(\frac{\mathrm{kwh}}{\mathrm{yr}}\right) * 0.5778\left(\frac{\mathrm{birr}}{\mathrm{kwh}}\right) = 42{,}361.522\mathrm{birr/yr} = \$1512.9$$

c) Greenhouse gas reduction

$$\mathrm{GGR} = \text{annual energy saving} * \text{C emission coefficient of electricity}\left(\frac{\mathrm{tC}}{\mathrm{Mwh}}\right) \quad (4.9.9)$$

$$\mathrm{GGR} = 73.31\left(\frac{\mathrm{Mwh}}{\mathrm{yr}}\right) * 0.1283\left(\frac{\mathrm{tC}}{\mathrm{Mwh}}\right) = 9.017\left(\frac{\mathrm{tC}}{\mathrm{yr}}\right)$$

d) Total energy reduction rate

$$\mathrm{TERR} = \frac{\text{annual energy saving}\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right)}{\text{annual energy consumption}\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right)} * 100\% \quad (4.9.10)$$

$$\mathrm{TERR} = \frac{16.86\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right)}{3473.92\left(\frac{\mathrm{toe}}{\mathrm{yr}}\right)} * 100\% = 0.48\%$$

e) Investment cost = 58,576 birr

| Section | Unit price | number | Total cost(birr) |
|---|---|---|---|
| T8 | 112birr | 523 | 58,576 |

f) Payback period of investment

$$P_b = \frac{\text{investment cost}\left(\frac{\mathrm{birr}}{\mathrm{yr}}\right)}{\text{annual cost saving}\left(\frac{\mathrm{birr}}{\mathrm{yr}}\right)} \quad (4.9.11)$$

$$P_b = \frac{58{,}576\mathrm{birr}}{42{,}361.52\left(\frac{\mathrm{birr}}{\mathrm{yr}}\right)} = 1.38yr$$

## 4.8. Energy Efficiency Improvement Techniques of Electric Motors

### a. Sizing to Variable Load

Electric motors most of the time working under different load conditions due to their requirements. A widely used method in selecting a motor size is based on peak load. But this leads the electric motor more costly when it works at full size for few times, and it conveys endanger of motor under-loading. Another option of selecting the motor capacity is depending on the load duration curve of a certain time. This load curve indicates that the selected motor capacity is a bit less than the peak load and results in overload for a short time. This is a good option because a motors manufactured with a service factor (usually 15% above the rated load) to operate the motors above the peak load for short time without causing damage under determined conditions. The chance of this kind of motor is overheating, which mainly influence the motor age, efficiency and results in increases running costs. The criteria in choosing the motor capacity is the average temperature increasing over the actual working time must not be higher than the temperature increasing under continuous full-load working time (100%) [39]. Overheating of electric motors can happen due the following cases:

- Utmost load variations, such as fast start and/or stop in short time, high starting load
- Recurrent and/or large time overloading
- restricted skill for motor to chilly down during overheating

### b. Adjustable Speed Drives (ASDs)

By adjusting the speed and the torque we can makes the motor to give only the required power as the load required because power equals to speed times torque. Where loads vary considerably with time, we can use speed regulating technique in inclusion to right motor capacity. Horsepower (HP) of a motor is represented by the product of torque and speed. A correctly designed motor will contest the power required by the load with the working conditions. But to exactly state a motor, it is not enough to be equal the motor capacity with the load capacity. The best factors used in determining performance and ability of the motor to answer to load variation are the speed and torque.

Motor in textile factory are working for long hours with variation in load and use high power. Electric drives are used with electric motors to decrease the electric power usage by alter motor speeds in operation that do not required to work always at full speed.

This altering of speed makes the motor power and energy use to pursue the load changes, rather than unwanted running repeatedly at full speed. Many times altering of speed drives mostly makes for textile factories to support the motor to use only the required power as the load needs. This can be made by altering the motor speed and/or torque to the recent load changes that can happen. In air compressor, the lines are regulated by making ON and OFF of motors. This recurrent starts and stop is high on motors and line equipment because of continuous tension from starting currents and acceleration and deceleration of mechanical equipment's.

Since air compressors are working repeatedly it may affect by endanger of harming the air compressor due to stretching too much, slipping and shatter. To minimize running cost, it is necessary to increase the compressor line lifetime and reliability. By using variable speed drives we can make flatten out line motion for better organized and successful in its work. These drives makes to have correct torque and speed regulation of air compressor and minimize the tension on mechanical materials such as gearboxes, pulley and belts mainly at the time of start-up and stopping but also during working time and maintenance. These drives regulate the speed of the air compressors to balance the production volume and the energy consumption [38][39].

Generally variable speed drives use minimum energy than fixed drives with similar performance. When loads changes, variable speed drives motors can often decrease electrical energy usage in centrifugal pumping and fan implementation by greater than or equal to 50% [40]. But comprehension the attribute or kinds of the load that can be used by the factory is specifically necessary, in determining either the speed change regulation is an opportunity. The best method for electricity savings with variable speed drives is mainly in variable torque operations.

**C. Rewinding**

In factories rewinding of burned electric motors is ordinary method of improving the performance of motor. In many factories the rewinding motors are above 50% of the total number of motors [40]. Cautiously rewinding of motors can most of the time keep motor efficiency at foregoing levels, however in some condition it results in decreasing efficiency. Rewinding influences the performance of motor by many factors which results in decreasing motor efficiency due to winding and slot design, winding material, insulation performance, and working temperature. Rewinding influences the performance of a motor because during rewinding when we apply heat to strip old windings the insulation between laminations can be loss which results in increasing eddy current losses. Another influence of rewinding of electric motors is during rewinding it may occur a change in the air gap which influences the power factor and output torque.

But if we make a right rewinding the motor efficiency can be keep similar in value with the designed efficiency. And in some conditions efficiency can be increased by using another winding design for example using large cross section of wires, allow slot size, would decrease stator losses and results in increasing efficiency. It is advocate the motor to keep the original efficiency after rewind, if not there are particular load-related menses for redesign.

The influence of rewinding on motor efficiency and power factor can be simply evaluated when the no load wastes of a motor are familiar before and after rewinding is made. Data on no-load wastes and no-load speed are occurring in the nameplate of motors and the suppliers give us in terms of manual when we bought.

The best practice whether rewinding of motors is prosperous or not is the contrast of no load current and stator resistance per phase of a rewound motor with the original no-load current and stator resistance at equal voltage.

To know whether rewinding of motors is important or not consider the following:

- Use a hard that ISO 9000 certified or is member of an Electrical Apparatus Service Association.
- Motors below 40 HP in capacity and working above 15 years old and mainly rewound before have efficiencies comparably below recently working energy-efficient designs.
- When the rewinding cost of motors is surpass by 50% to 65% of a new energy-efficient motor cost, purchase new efficient motor.

When we are rewinding a motor, it is necessary to select a motor service area that works based on the effective experience of motor rewinding rules and methods mainly to decrease energy efficiency wastes. These standards must be checked by the Electric Apparatus Service Association (EASA). When we made a best rewinding efficiency losses become less than 1% [41].

The factor helps to decide whether a rewinding motor is in good condition or not mainly depends on the present motor working conditions and the simple payback period related with the investment cost. Depending on manufacturer's view it is better to replace old motors mainly with annual working hour is beyond 2000 hours/year. In some cases even changing normally working motor with a surcharge efficient motor can result in low payback period [42].

**d. Improving Maintenance**

Mainly motor cores are done from silicon steel or decarbonized cold-rolled steel; these materials do not vary their electrical characteristics with age. But if the maintenance of these materials is poor it can lead worsen in motor efficiency in a short time and leads to less reliability in work and high running costs. For example, when our lubrication system is poor it leads in high friction in both the motor and other related drive transmission materials. Another impact of poor maintenance is the resistance losses of motor which increase with temperature will be increase.

Environmental/weather conditions can also affect the motor performance. For example, high temperatures, large wipe loading, caustic air, and mugginess can result to loss the insulation parts and mechanical tension because load cycling can cause to incorrect arrangement of the equipment's. When we made a good maintenance the motors life is long and we can understand the motor failure easily.

Motor maintenance standards are divided in to two these are preventative and predictive. Preventative standards include reducing voltage unbalance, load consideration, motor adjustment, greasing and motor venting. Motor maintenance through preventative standards helps to release increased motor temperature which consequences in increasing winding resistance, decreases motor life and rising energy use. The aim of predictive motor maintenance is to detect continuing motor temperature, quiver, and other working data to recognize when it becomes important to change/renew the motor before failure is happen. The energy saving link with ongoing motor maintenance is in the range of 2% to 30% of the total motor system energy use [43].

Proper maintenance is required to support motor performance. A catalog for better motor maintenance procedures includes the following:

- Examine occasionally for correct adjustment of the motor and the driven material.
- Examine load conditions to assure that the motor is over or under load. The motor load variation literally shows a variation in the driven load, the cause of which could be represents

the motor is greasing regularly. The manufacturers of the motors always give information on how and when to greasing their motors.

- Both poor and over greasing causes a problem on the motors, as discussed above. For example a problem caused due to over greasing is, if higher oil or lubrication from the motor relevance can go in for the motor and impregnate the motor insulation, it causes precocious abortion or creating a fire probability.
- Examine frequently for correct adjustment of the motor and the driven material. Poor adjustments can tenet the shaft and bearings to wear rapidly which results in destruction working to both the motor and the driven material.
- Make sure that supply wiring and terminal box are correctly sized and implemented. Cheek properly whether the link at the motor and starter are scrubbed and compact.
- Installing correctly the working venting and keep motor cooling conduit clean to help dissolute heat to decrease high losses and to make the life of the insulation in the motor longer: in every 10℃ rising in motor working temperature over the specified peak, the time before rewinding is believed to be half.

**e. Motor Management Plan**

A motor management plan is an important part of the factories energy management system.

Making maintenance on motors includes both predictive and preventive standards as element of a motor management design activates foresee and protect motor damage before it happen. If the managers have this data they get the chance to rearrange, rebuild, or change equipment's before damage happen and it helps to forecast when motor damage is happen and formulate to maintain appropriately. Motor management plan helps factories to perceive long-term motor system energy waste minimization and it will make the motor damage are minimized in a short time and cost successful way. The motor decisions matter SM campaign proposed the following important things for a sound motor management plan [44]:

- Making a survey on motors and preparing a program.
- Preparation of rules for changing recommendation.
- Constructing for motor damage by conceive a spares listing.
- Preparation of buying guidelines.
- Preparation of servicing guidelines.

### f. Replacing Energy Inefficient Motors by Energy Efficient Motors

The existing motors in the factory are inefficient and they cause less power factor, high energy cost and loss of energy. Therefore, we must change with energy efficient motors but to choose/select energy efficient motors we use motor master software.

The main cause for less efficiency of electric motor is under loading and it results in rises motor losses and decreasing the power factor.

Under-loading is the main reason for less efficiency of electric motors due to the following reasons:

- ✓ The manufacturers of the materials try to use high safety factor when they are choose the motor.
- ✓ Materials are not fully utilized. That is different machine tool materials are not working based on the manufacturers made to work within a full size based on the load materials. But practically, the customer may require sometimes this full size, which results in under-loaded working for long time and waste of energy and cost.
- ✓ Huge motors are choosing to qualify the output to keep at the required level even if the input voltages are irregularly low.
- ✓ Huge motor are choosing for implementation needed at high starting torque but a smaller motors designed to operate for high torque is also good.

The proper size of motors must be choosing based on attentive assessment of the load requirement. For example if the existing motor is large or above the load requirement we must replace with a proper sized motor but when we replace it is necessary to look at the potential efficiency of the new implemented motor because huge motors have essentially large rated efficiencies over smaller motors. If the existing motor working at 60 – 70% of its size or above it is not mandatory to change but if the factories motor works under 50% of full rated load, it is mandatory to change by huge, halved loaded or fully loaded motors either from factory catalog.

**Motor efficiency**: - is the ratio of the amount of mechanical work the motor accomplish and the electrical power it used to do the work expressed by a rate. A large rate of motor efficiency specifies the motor is more efficient motor but a less rate specifies the motor is inefficient. The motor master catalog specifies the costs of energy efficient motors are higher than those of standard motors therefore; to save the energy use we could to change the standard efficiency motor with higher energy efficient motors. When we need to buy a new motors and to change the existing older motors it is better to think about the cost of high efficiency motors. Consider the motor is working at constant speed, cost saving is calculated as:

$$\text{cost saving} = 0.746 * \text{hp} * \text{hr} * \text{rt}(\frac{1}{\text{Eo}} - \frac{1}{\text{En}})$$

Where: hp = motor capacity (in horsepower), hr = annual working hours, rt = utility rate in \$/Kwh, $E_o$ = Efficiency of the existing motor and $E_n$ = Efficiency of the changed motor [39].

**Motor Master Software**

Motor Master Software helps in choosing the right motor capacity and it helps for motor systems upgrading, by recognize the cost success, running cost due to the ongoing working of an existing standard efficiency motor to make conclusion on new choosing motor efficiency, on the rewinding or changing of the existing motor.

Motor master software is prepared by U.S. department of energy's best application program for the aim of [40],

- ✓ To compare the working condition of the existing motor with the right energy efficient motors
- ✓ To conclude on the changing of over loaded and under loaded motors
- ✓ To help to the motor users in choosing the right motor for implementation

In this thesis from this software we increase our consciousness on electric motor system efficiencies. Motor Master Software uses data values of the motor as input for the existing motor in the factory are taken from table. And the cost for the energy efficient motors is taken from the Motor Master Software catalogue. Table 4.16 shows the input and output data for specifying saving potential of electric motor using Motor Master Software. In this thesis Motor Master Software is used to know the difference between the correctly sized motors to its load and higher efficient motors with the existing inefficient motor. From figure 4.10 to figure 4.12 shows, how Motor Master Software chooses the right sized motor to particular operation and specifies the energy savings and cost wise of the efficient motors of the factory.

Table 4-16: Input and output data for examining saving of electric motors

| Input to the present motor | Input to energy efficient motors(from software catalog) | Outputs |
|---|---|---|
| Load<br>Power(kw)<br>Efficiency<br>Name plate speed(rpm)<br>Voltage(v) | Power(kw)<br>Load<br>Efficiency<br>Voltage(v)<br>Nameplate speed(rpm)<br>Purchasing cost | Energy<br>Demand<br>Saving<br>Payback period |

# CHAPTER FIVE

# ANALYSIS OF ANALYTICAL RESULTS, CONCLUSIONS AND FUTURE WORK

## 5.1. Analysis of Results

Based on findings of this thesis work the total electrical energy saving, thermal energy saving and greenhouse gas emission reduction are as listed below table 5-1.

Table 5-1: Result of improvements

| Improvement plan | | | Energy savings | | | | Total energy saving (toe/yr) | Cost saving (birr/yr) | Greenhouse gas reduction (tc/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Section | Facilities | Improvement | Fuel | | Power | | | | |
| | | | Kl/yr | toe/yr | Mwh/yr | toe/yr | | | |
| Heat part | 1.Boiler | Boiler air ratio control | 9.65 | 8.69 | - | - | 8.69 | 163,999 | 7.35 |
| | | Boiler flue gas WHR | 17.15 | 15.45 | - | - | 15.45 | 291,567 | 13.07 |
| | 2.Thermo boiler | Thermo boiler air ratio control | 5.36 | 4.8 | - | - | 4.8 | 90,507.15 | 4.05 |
| | | Thermo boiler flue gas WHR | 19.30 | 17.38 | - | - | 17.38 | 328,015 | 14.70 |
| | 3.Heat transport | Heat transport facility insulation | 8.68 | 7.82 | - | - | 7.82 | 147,600 | 6.62 |
| | 4.Dyeing machine | Dyeing machine WWHR | 18.91 | 17.04 | | | 17.04 | 321,521 | 14.42 |
| | | Dyeing machine adiabatic paint coating | 50.264 | 45.29 | | | 45.29 | 854,490 | 38.315 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Electric part | 5.Air compressor | Air compressor intake temp improvement | - | - | 16.632 | 3.83 | 3.83 | 9,700 | 2.134 |
| | 6.Llight facilities | T12 replaced by T8 lamps | - | - | 73.31 | 16.86 | 16.86 | 42,361.5 | 9.017 |
| Total | | | 129.3 | 116.5 | 90.3 | 20.69 | 137.13 | 2,249,760.7 | 109.676 |

## 5.2. Conclusions

We can conclude from energy auditing and conservation, energy efficiency improvement in factories is very important due to many reasons such as it saves energy consumption, it saves the cost we paid and it reduces the carbon emission to the environment by implementing energy waste minimization techniques and by using energy efficient equipment's.

That is by implementing energy efficiency improving techniques in the factory; the energy loss due to inefficient use of equipment's will be decreased. Through the improvements we save a total electrical energy of 90.3Mwh/yr(20.69toe), thermal energy saving is 129.304kl/yr(116.5toe) and total energy saving is 137.13toe/yr, carbon emission reduction by electrical energy is11.151tc/yr, by thermal energy 98.525tc/yr and the total carbon emission reduction is 109.676tc/yr and the cost saving by electrical power is 52,061.5 birr/yr.[ $1735.4], by thermal energy 2,197,699.15birr/yr($73256.64) and total cost saving is 2,249,760.65birr/yr[$74992], as we see in table 5-1. Therefore we can conclude from this research making energy audit on high energy consuming factories like textile is very important to save energy, money and to reduce carbon emission and to become the factory profitable.

## 5.3. Recommendations

It is recommended Quiha Maa Garment and Textile Factory to have energy audit team, to apply the improvements such as boiler air ratio control, boiler flue gas waste heat recovery, thermo boiler air ratio control, thermo boiler flue gas waste heat recovery, heat transport facility insulation, dyeing machine waste water heat recovery, dyeing machine adiabatic paint coating, air compressor intake temperature improvement, replacing T12 by T8 tube lamps and replacing less efficient motors by high efficient electric motors in to practice and to study other improvement opportunities such as thermo-oil heat source change using at dryer, dyeing water ratio control per batch of dyeing machine, solar heat system installation, garment ineffectiveness power flow meter replacement, changing roots blower to turbo blower and thermo oil circulation pump inverter operation. Through these improvements a large energy is saved and a lot of money will be saved therefore the factory must apply to practice these improvements and other researchers must do on these and other improving opportunities and tries show their benefits in terms energy saving, cost saving and greenhouse gas emission using mathematical analysis.

## 5.4. Suggestions for Future work

Based on this thesis work, the following future works are suggested to other researchers:

1. To study and compare the use of thermal energy and solar energy for the thermo boiler in terms of energy consumption, cost effectiveness and carbon emission.
2. To carry out studies on dyeing water ratio by comparing with standard water ratio and try to show whether the existing dyeing water ratio is cost effective by calculating the energy consumption during the existing water ratio and when we use the standard.
3. Since the thermo boiler oil circulation pump is working even when the stenter and dryer machines are not working which results in wastage of energy. Therefore, methods may be investigated that would stop the thermo boiler oil circulation pump if the stenter and dryer machines are not working.

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