

Energy Audit on Awash Melkassa Aluminium Sulphate and Sulfuric Acid Share Company

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December, 2018

Energy Audit on Awash Melkassa Aluminium Sulphate and Sulfuric Acid Share Company

M.Sc. Thesis

By

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A Thesis Submitted to Thermal and Aerospace Engineering Department of
School of Mechanical, Chemical and Materials Engineering, Adama Science
and Technology University in partial fulfillment of the requirement of the
degree of Master of Science in Thermal Engineering.

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Adama, Ethiopia

December, 2018

Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by SINTAYHU SHIFRAW have read and evaluated his/her thesis entitled "Energy Audit on Awash Melkassa Aluminium Sulphate and Sulfuric Acid Share Company" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirement of the Degree of Masters of Science in Thermal Engineering.

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Declaration

I hereby declare that this M.Sc. Thesis entitled "Energy Audit on Awash Melkassa Aluminium Sulphate and Sulfuric Acid Share Company" in partial fulfillment of the requirement of the degree of Master of Science in Thermal Engineering is an authentic record of my own work carried out from September 2017 to December 2018 under supervision of Dr. Gezahegn Habtamu, Assistant Professor of Thermal Engineering department, Adama Science and Technology University.

The matter embedded in this thesis has not been submitted for the award of a degree or diploma in any other university. All relevant resource information used in this paper has been duly acknowledged.

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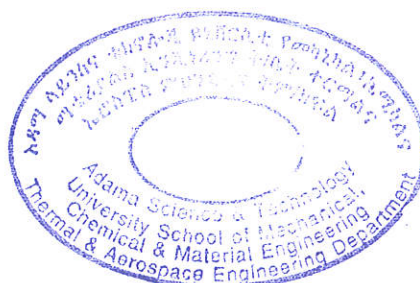
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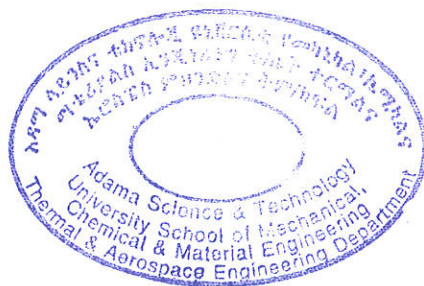
ACKNOWLEDGMENT

I am very grateful to my adviser Dr. Gezahegn Habtamu, for providing the impetus, the means and the support that enabled me to work on this thesis. I deeply appreciate his concern and the appreciation and encouragement he provided to enable me to become a professional. He has been an exemplary mentor and I thank him for his guidance and insights in my thesis. I especially appreciate the way he treats his group members and his peers.

I also thank my co-adviser Mr. Samuel G/Mariam (MSc) for his comments of my thesis in our weekly meetings and his support and guidance was indisputably helpful for the progress of my work.

I would like to express my sincere gratitude to Mr. Mebratu Yishak for his support throughout my work and to extend my thanks to group members of all AMASSASC employers and specially group of technical managers Mr. Tesfaye, Mr. Getachew H/wold, Mr. Tefera and Mr. Gemechu for providing such a good atmosphere, and to all the people I met in the factory and with whom I spent a nice time.

Finally I would like to thank my family for all their support and always encouraging me to work hard.



EXECUTIVE SUMMARY

Energy utilization in Ethiopia increased rapidly since few years because of the economic development and population growth of the country. In order to fulfill the increasing energy demand, the country is to constructing hydroelectric power plants and cogenerating plants (sugar industries). But still there is a huge gap between the supply and demand of energy.

The main objective of this thesis is to carry out an energy audit of Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company and identify energy conservation opportunities.

AMASSASCo produces Aluminum Sulphate and Sulfuric Acid uses fuel and electricity as primary source of energy to generate thermal and electric energy to follow its production. All the thermal energy developed by the boiler is used to keep the molten sulfur and other purposes. Most of the electricity is used to power different electrically driven systems of the factory. Both the fuel and electricity consumption patterns of the factory are known and are variable from one month to the other. The consumption of fuel and electric energy are large for month of Nov, 2009 E.C 82,836 liters and 203,336 kWh respectively. The price of fuel and electricity on local market are 16.5 Birr/liter and 0.55 Birr/kWh respectively.

Energy audit is the process of studying the production process, the energy bill analysis and equipment's in the production systems and their energy efficiency, identifications of energy conservation measures and technical and economic feasibility analysis for the identified energy conservations opportunities. Data were collected for a period of five consecutive years (2005-2009EC) on energy performance of AMASSASC and the analysis can be carried out.

The energy systems (Thermal and Electrical) of the factory were inspected to identify Energy Conservation Opportunities and major energy consuming systems of the factory were identified. These major energy-consuming systems are boiler and their steam distribution systems, pumps and air compressors with their prime movers.

The data for the major energy consuming systems were collected by using different portable measuring instruments, from nameplates (machine specifications), readings from the gauges installed on the energy systems, visual inspection, interview, referring factory log sheets and record books to perform energy analysis of AMASSASCo proper utilization of energy. During the audit analysis the causes for the efficiency loss of boiler were identified to be excess air admitted into the boiler was greater than the recommended value of 15 %; absence of appropriate boiler maintenance; improper water treatment; absence of automatic

blow down control system which leads to excessive blow down and mismatch of steam supply and demand in the factory. Using the standard energy balance was conducted to determine the boiler efficiency and the corresponding Sankey diagram. The result obtained efficiency of boiler was 72.3 % by direct method. This indicates the energy of fuel was lost on GCV. Using heat balance method the efficiency of boiler was 72.7 %. However, the recommended efficiency of fuel-fired boiler is about 85 %. This indicates that the efficiency of factory boiler is lower.

Energy conservation measures suggested among various energy conservation opportunities identified with energy and cost savings.

Repairing boiler feed water treatment plant, insulating boiler surface, replacing existing boiler, energy and cost saving were 2,731.58 kW and 9,628,434.5 Birr/year.

Controlling excess air by controlling fan speed and insulating main steam distribution systems, energy and cost savings were 112.33 kW and 495,081.93 Birr/year

Replacing pump with motors energy and cost savings were 14,231.8 kW and 82,710.3 Birr/year respectively.

In conclusion, there are also many housekeeping energy conservation opportunities, which can be done with no or low cost by the factory workers, which are

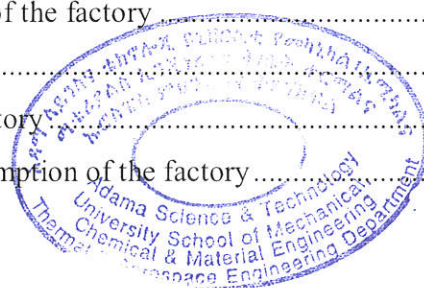
- Periodic remove scale from the boiler waterside
- Periodic removal of soot from boiler chimney
- Replacing the worn-out valves
- Insulate the bare steam lines
- Avoiding leakage from pumps
- Systematically control the compressed air distribution line valves
- Avoiding steam leakage from distribution system
- Cleaning all machines in the factory regularly
- Giving updated awareness on energy management to the factory workers

From these measures, the factory should have a clear image of its energy handling practice and take all the possible measures to become energy efficient and competent.

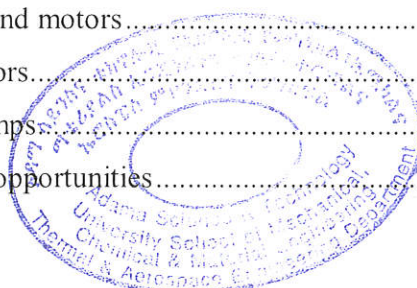
The ECOs action plan for the factory was developed for implementing the above energy saving measures, which the factory can use for improving its energy efficiency.

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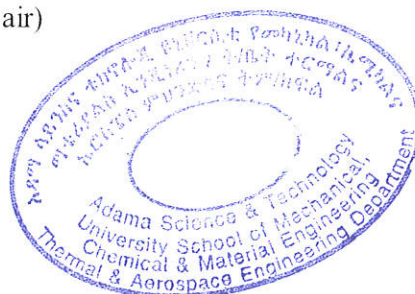
LIST OF ABBREVIATIONS

AMASSASC Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company

EC	Electricity cost
ECO	Energy conservation opportunities
EEAC	Electric energy amount of consumption
EEPC	Ethiopian electric power corporation
FC	Fuel cost
FEAC	Fuel energy amount of consumption
GCV	Gross calorific values
GTP	Growth transformation plan
HEM	High efficiency motors
MWH	Mega watt hour
NCV	Net calorific value
PCA	Portable combustion analyser
PRS	Post reaction suspension
TDS	Total dissolved solids
TPH	Ton per hours
VSDs	Variable speed motors

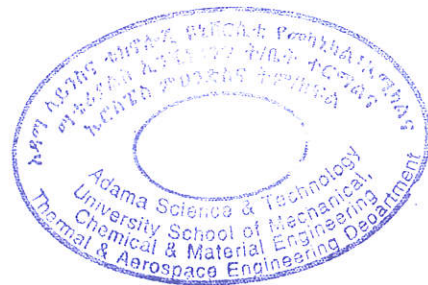
SYMBOLS

Q	Heat energy (kW)
C_p	Specific heat (kJ/kg °C)
T	Temperature (°K or °C)
h	Enthalpy (kJ/kg)
P	Pressure (bar or Mpa)
$\dot{V}$	Volume flow rate (m ³ /sec)
$\dot{m}$	Mass flow rate (kg/sec)
γ	Humidity factor (kg of H ₂ O/kg of dry air)
ϕ	Relative humidity (%)
ρ	Density (kg/m ³)
V	Voltage (v)
I	Current (A)
$\cos\theta$	Power factor
η	Efficiency (%)



SUBSCRIPTS

A	Absolute
am	Ambient
at	Atmospheric
bs	Back surface of boiler
bd	Blowdown
comb	Combustion
cs	Cylindrical surface of boiler
w	Feed water
fs	Front surface of boiler
f	Fuel
st	Steam
gs	Super-heated steam
s	Surface
th	Thermal
ts	Total surface area of boiler
fg	Vaporization of water



SUBSCRIPTS

A	Absolute
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CHAPTER ONE

1. INTRODUCTION

1.1. Background

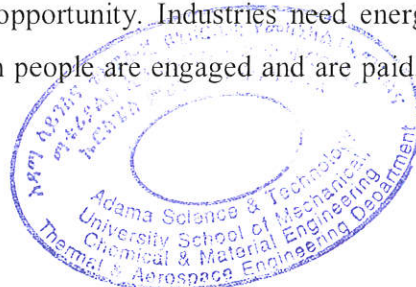
Energy utilization in Ethiopia increased rapidly since few years because of the economic development and population growth of the country. In order to fulfill the increasing energy demand, the country is constructing hydroelectric power plants and cogenerating plants (sugar industries). But still there is a huge gap between the supply and demand of energy [13].

The Ethiopian government has clearly identified the role of energy for its economic development. According to Ethiopian energy authority, the installed electric energy production capacity is expected to move from currently available 2000 MW to 8000 MW-10000MW by the end of the Growth and Transformation Plan (GTP 2015). To construct the energy projects and to bring reliable energy to the country, the government has to also rebuild the operating and regulating institutions to control the energy sector in the country. Ethiopian energy authority is one of the institutions to control the energy sectors, directed with increasing energy efficiency in the industries and other sectors. However, energy production is not the only way to address the energy supply. An appropriate utilization of energy is also one of the key strategies where by a huge amount of energy conserved. Energy conservation, which is an appropriate utilization of energy, can alleviate the burden of the ever-growing energy demand [12].

In addition, to constructing new power plants, the country must evaluate the proper and efficient use of energy it produces by its limited energy generating organizations. Most of the time electrical and thermal energy are wasted in industrial, commercial, household and different sectors because of use of insufficient use of equipment's, machinery and other energy consuming systems [20].

Energy conservation is a global issue as its production is mostly related to environmental pollution and degradation. The appropriate utilization of energy is equivalent to protecting the environment, which is a global issue [12].

Energy conservation also related to job opportunity. Industries need energy for their function. They are the hubs of jobs on which people are engaged and are paid. Therefore,



energy conservation is a job opportunity. Its conservation paves the way for more job opportunity.

One of the key measures of energy conservation is energy audit. Energy audit is systematic account of energy and its utilization.

In the industrial sector, energy is consumed for wide range of activities, such as processing, space conditioning, and lighting. In combined, the industrial sector uses more energy than any other end-use sector, consuming about one-half of the world's total delivered energy [17].

There are different energy consumer industries such as chemical, sugar, textile, cement etc. Chemical industries are one of the energy-intensive plants that use electrical and thermal energy [12].

In our country, most of the industries are constructed many years ago and because of service year, the consumption of energy becomes increase year to year. For example, Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company were established in September 1987 EC. Within these 22 years, an energy audit was never carried out in Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company (AMASSASC).

The main product of AMASSASC is Aluminum Sulphate and Sulfuric Acid. Aluminum Sulphate is mainly used for water treatment, textile, cola, and paper and pulp production industries. Sulfuric Acid is widely uses by textile, leather and car battery industries are some of consumers of this product [9].

The input required for the production of Aluminum Sulphate is locally found except Aluminum Hydroxide, it is imported in small amount. Kaolin is the main raw material and supplied by Ethiopian Mineral Development Share Company from Oromiya Borena Zone. The production of sulfuric acid supplied from locally except Sulfur, which is imported [9].

Because of service year of the industry, there are energy losses and wastes at different electrical and thermal equipment's. Therefore, application of energy audit technique helps in identifying major areas of energy losses and wastes takes place in the factory.

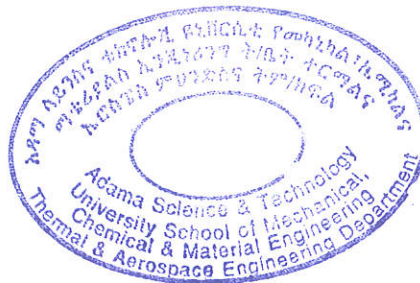
AMASSASC uses both electrical and thermal energy to drive various equipment's like motors, pumps, boilers, compressors, diesel generating engines and furnace. However, many problems in the factory prevent it from efficiently using its energy. The factory personnel's are not well aware on the concept of energy conservation. Due to this, the factory losses more on energy bills.

To overcome the energy losses and wastes in industries to apply energy audit and management to the industries. An energy audit will help to understand more about the ways

energy and fuel are used in many industries and help to identify the area where the energy waste occur and where the possibility of reducing energy losses in the AMASSASC.

A good management of energy in the company will be important degree of its performance. Improving the energy use in the factory will enable it to be competent and to remain in the market. Besides, it reduces the environmental load and related disasters caused by combustion by exhaust gases [10].

The aim of this thesis work is to identify the main energy-consuming units and to find a possible solution to tackle the recognized troubles. A thorough thermal and electrical performance assessment of corresponding units has made to discover inadequately functioning units. Thermal performance of major equipment's and processes are assessed for main thermal units including boilers, steam distribution lines, etc. Hence, this thesis research examines the energy consumption pattern of the factory and efficiency of the major energy consuming systems and devices thereby identifies energy conservation opportunities to save energy and prepare energy audit documentations for the factory.



1.2. Statement of the problem

Ethiopia has the problem of proper utilization of energy in most factories. They did not know their energy consumption patterns in well-defined manner by performing energy audit. This is due to the following reasons.

- Lack of skilled human resource in energy management,
- Lack of updated awareness for the factory workers about energy management,
- The absence of measuring instruments for audit,
- Absence of energy audit team in the factories, etc...

Therefore based on these facts, this thesis focuses one of the selected chemical industry in Ethiopia Awash Melkassa Aluminum Sulphate and Sulfuric Acid Factory, which is so old 22 years and has so many energy related problems to conduct energy audit. The observed problems in the factory signify that it should conduct energy auditing.

In Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company, the most operating costs are found to be energy and labor. In this case, the energy utility being electricity and fuel used to drive all production process. The electrical and thermal equipment become very old, because of this, the consumption of electric and fuel increases year to year, so there are energy losses and wastes.

Hence, this thesis is aimed to observing the energy consumption patterns of the factory and efficiencies of the major energy consuming systems in that way identifying energy conservation opportunities to save energy for the factory to make it more competitive in the market.

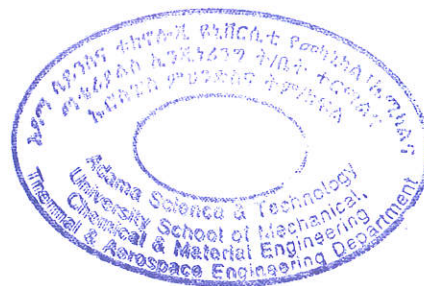


1.3. Objectives of the thesis

The main objective of this study is to carry out energy audit of Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company and identify energy conservation opportunities.

The specific objectives of the thesis research are

- ✓ Study the facility and production process of Al_2SO_4 (Aluminum Sulphate) and H_2SO_4 (Sulfuric Acid).
- ✓ Analyzed energy consumption pattern of the industry for the last 5 years.
- ✓ Perform detail energy audit of the factory.
- ✓ To identify energy conservation opportunities and carry out economic feasibility analysis.
- ✓ Write the energy audit report.



1.4. Significance of the thesis

Performing energy audit and identify areas where energy wastages can be reduced will be economically beneficial not only to the company but also to the country energy sector. This will also benefit the company to fully establish a good energy management plan.

Some benefits of this thesis are:

- ✓ It leads to find out possible problems or malfunctioning, in order to avoid power peaks and other situation of energy waste.
- ✓ It allows verifying that the amount of energy consumed does not exceed the necessary.
- ✓ It helps to increase the life span of the equipment in AMASSASC facility.
- ✓ It discovers any unaccounted consumption that may exist at the facility.
- ✓ Easy to understand technical information regarding the proposed energy conservation measures.
- ✓ Identifies energy losses for corrective action.
- ✓ Impact of operational improvements can be monitored.
- ✓ Reduces the specific energy consumption and operating costs by systematic analysis.
- ✓ Improves the overall performance of the total system and the profitability and productivity.
- ✓ It helps to reduce environmental damage and pollution.
- ✓ Prevents equipment failure.
- ✓ Estimates the financial impact on energy consumption projects.
- ✓ Serves as a very good self-auditing cum correction system for performance improvement.
- ✓ No extensive training/calculations are involved.
- ✓ Reduces consultancy charges drastically.
- ✓ It can reduce the consumption of natural resources.



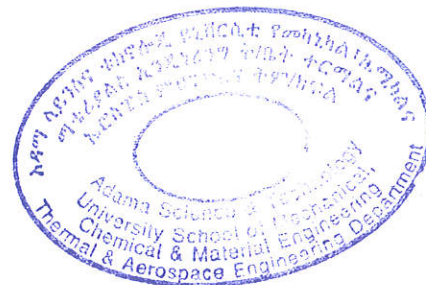
1.5. Research methodology

In this study, the audit covers all the electrical and thermal energy consuming equipment's and also details assessment of the processes. The audit includes all the major energy consuming equipment such as boilers, pumps, water pumping systems and air compressor etc. It is also carried measurements and analysis of all energy consuming sections, to assess losses and energy saving.

And also performances of the major energy intensive equipment's like motors, pumps, Air compressor are assessed. Then the data are analyzed quantitatively and qualitatively. Depending on the assessed data opportunities to reduce energy losses are done. From the analyzed data, conclusion and recommendation have been forwarded.

To conduct and realize the objectives of the thesis the following methodologies were adopted for this audit.

- Literature survey on energy audit
- Site visit and interview
- Observations on the general condition of the facility and equipment
- Visual inspection
- The energy consumptions of the factory for the last five years.
- data collection
 - ✓ Information was gather from a number of sources such as billing information, data loggers, interviewing the workers/maintenance engineer/staff and many hours spent on site.
- Identification/verification of energy consumption and other parameters by measurements
- Perform desk top analysis
- Detailed calculations and analyses
- Potential energy saving opportunities by
 - ✓ Performing technical evaluation
 - ✓ Performing economic evaluation
 - ✓ Calculating simple payback periods
- Locating list of energy conservation measures
- Prepare energy action plan



1.6. Structure of chapters

This thesis research is organized in eight chapters that all are necessary in energy audit report arrangements.

Chapter one discusses general description of energy, need of conducting energy audit at AMASSASC, the research problem, the general and specific objectives of the research, significance of the research and research methodology.

Chapter two presents the literature review based on local and international paper were review.

Chapter three presents brief introduction of Aluminium Sulphate and Sulfuric Acid Share Company including: its organizational structure, staff profile, operating hours, electricity, fuel and water usage of the factory. Description of both production lines also present in this chapter.

Chapter four present the factory energy bill analyses, energy consumption patterns, identifications of nine energy consumption area, preliminary energy audit, and inspection of the major energy systems of the factory to discover no/low cost energy conservation opportunities and major energy consuming systems of the factory that required detail energy audit analysis.

In chapter five, the detailed energy audit of the boiler was discusses to discover its energy conservation opportunities and to take the feasible energy conservation measures.

Chapter six present the detailed energy audit of pumps with their motors and compressor with motor discussed here.

In chapter seven discussed the short term, medium term and long-term energy action plan and summarizes the technical and economically feasible energy conservation opportunities.

In chapter eight, conclusions, recommendations and future work of the research are present.



CHAPTER TWO

2. LITERATURE REVIEW

The work has been studies local and international energy audit were review as discussed below.

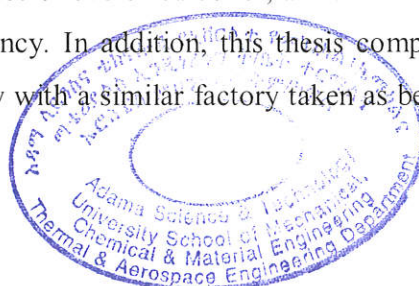
2.1. Local energy audit research

Mebratu Yishak (2014) conducted energy audit in Ethiopian Pulp and Paper Factory. He focuses on the drier section of the paper and pump and its drive system. The factory uses 100% electrical energy to produce steam. When he investigates the factory uses 9.3 GJ/ton but recently the factory consumption jump to 14 to 15 GJ/ton. According to his conclusion there are so many technical and operational reasons because of age of the factory it's about 50 years old. In addition to this, he mentioned that the factory should renew its energy consuming system. [28]

- Intensive and quality maintenance.
- Modernization of the systems of the factory to enable itself competent in the world market.
- Installation of modern process control systems so that down time and rework would be minimize.
- Replacement of old systems by new ones.

Feleke bayu (2014) carried out energy audit in Mughar Cement Enterprise (MCE). The result of this study revealed that MCE has enormous opportunities to save both thermal and electrical energy. Proper and stable kiln operation can reduce energy consumption and maintenance costs, increase kiln output, and improve overall production quality. It concludes that the root causes of high energy losses are resulted from improper design of equipment's and operational incompetence. This paper focuses on the kiln section because in this section thermal and electrical consumptions were more. [15]

Samuel G/Mariam (2009) studied "Energy audit of Mekanisa Alcohol Factor". This paper identifies the major energy consuming systems in the factory. The systems were boiler, distillery columns, pumps, air compressors, and their prime movers. The research also discussed the problems of the factory. Such as use of oversized boiler, untreated boiler feed water, unknown combustion and boiler efficiency. In addition, this thesis compared and analyzed the energy consumption of the factory with a similar factory taken as benchmark [34].

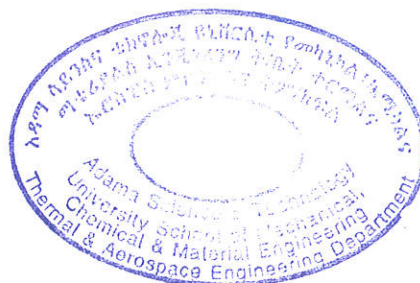


Yibeltal Abiy (2011) performed energy audit in Sebeta Alcohol and Liquor Factory. This study focus on the major energy consuming units such as boiler and its steam distribution system, distillery column, pump, compressor with their drive. After applying the detailed audit for energy consuming units the factory uses thermal and electric systems inefficient. In conclusion, many energy conservation measures were taken to increase the energy utilization performance of the factory by upgrading energy efficiencies of the end use devices in the factory. The major ECMs were recommend with respective saved energy, cost of saved energy, implementation cost, payback periods and many major ECMs from the conducted detail energy audit for different system units and many housekeeping energy conservation measures to help the factory reduce its energy cost [35].

Samson Mekbib (2008) carried out Industrial Energy Efficiency in Ethiopia Tannery. It covers energy audits of the factory and efficiency of the boiler. Boiler efficiency describes the ways that the boiler plants waste energy to various subsystems of the plant. Identifications of energy conservation opportunities and take an action for the energy saving measures using energy audit procedures. Using simple payback period analyzed technical and economic analysis of different energy consuming systems [33].

Lemlem Haftom (2015) studies on Energy Utilization and Efficiency Improvement Opportunities of Messebo Cement Factory. This thesis gives attention energy utilization and efficiency of electric motors and their energy saving opportunities. The high cost or capital-intensive measures may need further detailed audit and analysis. However, the results of the study should be used as a guideline for future expansions and purchases of new machineries [24].

Marishet Kebede (2014) this study has assessed energy efficiency and power quality improvement in Arbaminch Textile Factory. In general, energy in Arbaminch the textile industry is mostly used in the forms of: electricity, as a common power source for machinery, cooling and temperature control systems, motor systems, steam generation, etc. The results of the thesis have showed that unnecessarily energy is lost in the factory due to the existence of low energy efficient motors, Accessories, etc. Thus, replacement with energy efficient equipment's and proper use is necessary. By implementing the energy efficiency and power quality improvement opportunities in this thesis work, the factories can get 1,300,000 birr per year benefits [27].



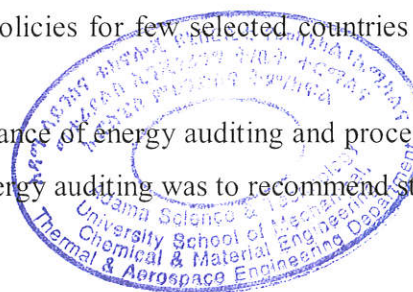
2.2. International energy audit studies

Chan et al. (2010) performed on site energy audits of 118 firms in the Taiwanese Iron and Steel Industries during 2000-2008. They reported total potential energy savings of about 79,160.8 kL of crude oil equivalent. They identifying potential electricity savings of 70,322.8 MWh, fuel oil savings of 22,235.1 kL, steam coal savings of 4922 tons, and natural gas savings of 10,735 km³. This amount is a total reduction of 217,866.5 tons in carbon dioxide emissions, equivalent to the annual carbon dioxide absorption capacity of a 5836-hectare plantation forest. This study had established a national database presenting information and energy saving methods for energy users and identified the potential areas for making energy savings to provide energy conservation reference. It was helpful to the energy users in performing energy audits and increasing energy utilization efficiency [6].

Hasanbeigi and Price (2010) provided guidelines for energy auditors regarding the key elements required for preparing an energy audit, conducting an inventory and measuring energy use, analyzing energy bills, benchmarking, analyzing energy use patterns, identifying energy efficiency opportunities, conducting cost-benefit analysis, preparing energy audit reports, and undertaking post-audit activities. They were assisted to the energy auditors and engineers to conduct a well-structured and effective energy audit [16].

Abdelaziz et al. (2011) conducting a review of industrial energy saving by management, technologies and policies. Latest literature in terms of thesis (MS and PhD), journal articles, conference proceedings, web materials, reports, and books, handbooks on industrial energy management, policies and energy savings strategies compiled. Energy saving by management including energy audit, training programs and housekeeping beside some energy management practices in the world was review. Energy saving technologies, such as use of high efficiency motors (HEMs), variable speed drives (VSDs), economizers, leak prevention and reducing pressure drop was review. Based on energy saving technologies results, it was report that in the industrial sectors, a sizeable amount of electric energy, emissions and utility bill could be save using these technologies. Payback periods for different energy savings measures were work out and found to be economically viable in most cases. Finally, various energy saving policies for few selected countries were report [1].

Kumbhar and Joshi (2012) studied importance of energy auditing and process of energy audit in industrial sector. Their purpose of energy auditing was to recommend steps that can



be taken by management for improving the energy efficiency, reducing energy cost and saving the money on the energy bills. They found that the recommended low cost operational changes in an industry saved 10-20 % on capital cost of utility bill with payback period of two years. Their approach was useful for an industry in combating essential energy cost and encompassed several other benefits like improved production, better quality, higher profitability and the satisfaction of contributing in saving energy [23].

Nangare and Kulkarni (2012) studied the energy utilization in sugar industries of Maharashtra state. Their study revealed that in all sugar industries about 40 to 50 % of extra feed air supplied to combustion chamber resulted 10 to 15 % of energy losses through exhaust gases. Further, they concluded that sugar industries should go with co-generation option, which resulted 10 % of increment in total electricity generation through this work [30].

Madhav and Ramesh (2012) conducted research work on “Heat Recovery through boiler blow down tank” they have given suggestions as “Blow down water carries thermal energy in the form of steam that can be reused may result in improves the boiler efficiency. Blow down heat recovery system may provide you with significant savings to the boiler plant i.e. from this study reveals total energy saved =625.57 kJ/S [5].

Krishnanunni and Josephkunju (2012) have done the research work on “Evaluation of Heat Losses in Fire Tube Boiler” using empirical and experimental methods and they have given the valuable suggestions like “The heat losses in dry flue gas and due to unburned fuel are interrelated. Therefore, they can be control by the same method. Installation of Zirconium oxygen sensor was suggest as the remedy for both the problems. This instrument can reduce the stack loss approximately 3.5% and boiler efficiency can be improve from 80 % to 83 % [22].

Maheswaram et al. (2012) presented case studies of various energy efficient techniques used in steel plant. They operated electric motors to drive industrial processes, and auxiliary systems, compressed air generation, water pumping. Approximate half of the electricity was use to drive electric motors [26].

They provided some of the recent trends in energy efficiency technologies that had been successful and widely used worldwide. They are

- Energy efficient motors
- Soft starters with energy saver
- Variable speed drives
- Energy efficient pumps



The combination of occupancy sensors and lighting control system resulted the total energy saving of 27275 kWh per year. They attempted following key challenges due to increasing the efficiency of systems, which was drive by electrical machines:

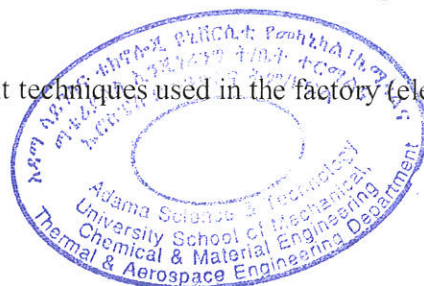
- Firstly, extend the application areas of variable-speed electric drives through reduction of power electronic and control costs.
- Secondly, to integrate the drive and the driven load to maximize system efficiency.
- Finally, to increase the efficiency of the electrical machine.

They concluded that the considerable electrical energy savings varying from 10-15 %.

2.3. Conclusion from literature reviewed

The following points are extract from the above review papers.

- The processes of the factory, boiler, pump and air compressor with their driven system were studied.
- Relevant data were collect by site visit, interview, walk through, etc.
- Use portable measuring instruments like portable gas analyzer, thermocouple, flow meter, etc.
- Identify major energy consuming systems in the factory.
- Compared and analyzed the energy consumption of the factory with a similar factory.
- Performed site energy audit of different factory and identifying potential energy savings of electricity, fuel oil, steam.
- Provided guidelines for energy auditors regarding the key elements required for preparing an energy audit, analyzing energy bill, analyzing energy use patterns, identifying energy efficiency opportunities, conducting cost benefit analysis and energy audit reports.
- Review industrial energy saving by management, technologies and policies.
- Conduct simple payback periods for different energy saving measures.
- Importance of energy audit, process of energy audit in industrial sector and energy utilization in the factories.
- Provides evaluation of heat losses in fire tube boiler using empirical and experimental methods.
- Conclude various energy efficient techniques used in the factory (electric motors, pump and air compressor).



CHAPTER THREE

3. INTRODUCTION TO AMASSASC

3.1. Background of AMASSASC

Awash Melkassa Aluminum Sulfate and Sulfuric Acid Share Company (AMASSASC) is the biggest chemical factory in Ethiopia constructed through the year of 1982-1987 EC with an initial investment of about 108 million birr on the total area of 14 hectares. It is the only chemical company in Ethiopia that produces aluminum sulfate and sulfuric acid.

The factory is located in the town of Awash Melkassa which is 18 km from Adama. The state-owned company currently produces around 13,600 ton of aluminum sulphate, 17,000 ton of sulfuric acid, 5000 ton Oleum and 5500 ton Hydrogen peroxide annually, which are used in the production of leather, car batteries, cotton, and for water treatment.

Awash Melkassa Aluminum Sulfate and Sulfuric Acid Share Company produces the four major chemicals such as Aluminum Sulfate (Al_2SO_3), Sulfuric Acid (H_2SO_4), Oleum and Hydrogen Peroxide. However, hydrogen peroxide production were currently block because of commissioning (audit time).

The supplier of the production machine and equipment's is Poland Company "CHEMADEX". The company was design to produce Aluminum sulphate, Sulfuric Acid and Oleum. Currently production of Oleum was not produce [9].

AMASSASC produces all this products by utilizing partially raw materials available locally. The capacity of the plant is currently sufficient to cover the country requirement of the chemicals and fulfilling the import substitution objective of the country though it is a very small quantity, the company also exports its products to Sudan. (Industry catalogue) [2].

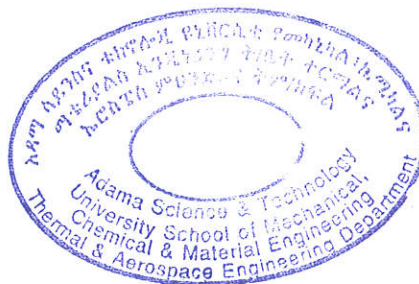




Figure 3-1 AMASSASCo factory view

3.2. Description of the process plant

3.2.1. Sulfuric acid plant

3.2.1.1. Solid sulfur

Solid Sulfur is periodically supplied from store by means of shovel loader to sulfur tank wherefrom it is feed by means of batcher to melting tank indirectly heated with steam and agitated with paddle agitators to intensify sulfur melting.

Solid sulfur is mixed with liquid sulfur by means of agitator. Sulfur melting tank is a two chamber earth tank. In the first chamber there is melted sulfur, and from the second chamber melted sulfur is pumped to the filter, and after filtration flows down to pure sulfur tank. Diatomaceous earth as filter aid is added to melted sulfur from tank. From the tank sulfur is fed to burner using a pump.



3.2.1.2. Sulfur burning and SO₂ conversion

Liquid sulfur is burnt in furnace in oxygen atmosphere from heated dried air. Sulfur and a part of the air are fed to burner. Some air is supplied to the furnace chamber. As a result of combustion, there is a gas receiver which can contain 9.5 % by volume of SO₂ at temperature 1066 °C. In order to cool the gases to a temperature of 420 °C the gases are directed to steam boiler for utilization of considerable part of the heat contained in them which is utilized for the production of saturated steam at pressure of 2.128 MPa, and temperature of 214 °C. The gases, on cooling down are directed to a converter where conversion of SO₂ to SO₃ takes place. The converter has four plates with vanadium catalyst. The conversion grade is 98%. Conversion of SO₂ to SO₃ accompanied by a positive power effect giving temperature increase of oxidized gases. The oxidization heat is utilized in air heater, water pre-heater, evaporator, and also for the production of steam. For the starting of the plant there is oil burner installed on sulfur burning furnace, waste gases flow through boiler, starting heater, are directed into the atmosphere.

In the heater dried air is heated to be used for drying brick linings just before start up, catalyst as well as for raising the contact section temperature up to catalyst ignition temperature, i.e. 420 °C.

Table 3-1 Temperature and conversion

Bed		Temperature (°C)	Conversion (%)
Bed1	Inlet	410	74
	Outlet	602	
Bed2	Inlet	438	92.4
	Outlet	485	
Bed3	Inlet	432	96.7
	Outlet	443	
Bed4	Inlet	427	98
	Outlet	430	

3.2.1.3. Air drying and SO₃ absorption

Air is sucked in by blower from environment through filter, and after compressing is directed to drying tower, in the drying tower the air is dried by contacting 98 % sulfuric acid, circulating in the tower recycle circuit, circulating tank, pump, cooler, in the top section of the drying tower demister is placed. The dried and demisted air is heated in heat exchanger and partly directed to furnace, and the remaining part of it is directed straight to fourth plate

of converter for directly cooling down the gas downstream of third plate. In the absorption tower there takes place SO_3 absorption from the gas-leaving converter, cooled in heat exchanger. SO_3 is absorbed by 98 % H_2SO_4 in the recycle circuit. Absorption tower, circulating tower, pump, cooler, post-absorption gas is demisted in the demister installed on the top section of absorption tower, and directed to stack. The concentrated sulfuric acid flows down by gravity law from absorption tower to circulating tank to which process water and dilute sulfuric acid are supplied from drying tower.

In order to maintain acid concentration at desired level, in the circulating tank there is installed concentration meter controlling the rate of supplied process water, liquid level in circulating tank is controlled by level indicator. Acid surplus is withdrawn from the recycle circuit automatically through control valve level indicator controller. The acid is directed via cooler to storage tanks. In case there battery grade acid is produced, to the circulating tank there will be a supply of demineralized water. Dissolved sulfuric acid will be withdrawn from the circuit of drying tower using pump and after cooling in cooler directed to tank or to fillers.

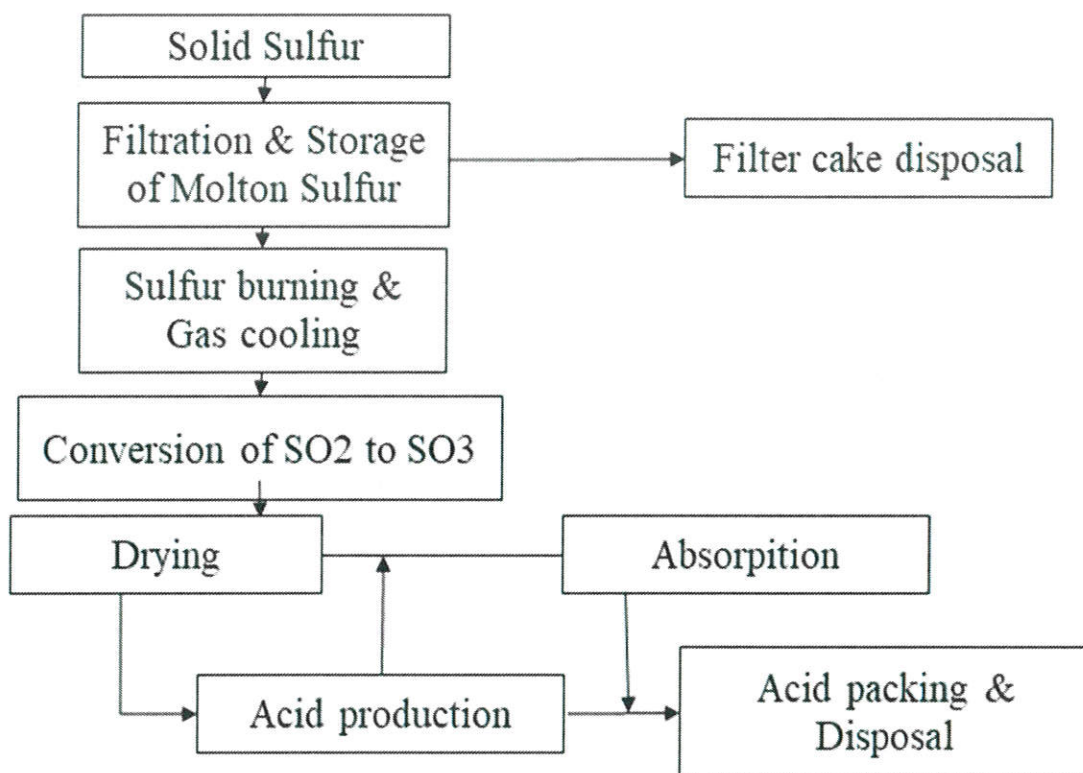
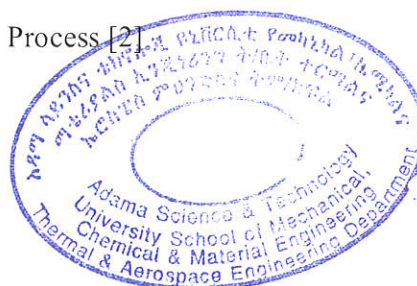


Figure 3-2 Sulfuric Acid Plant Process [2]



3.2.1.4.Storage and dispatch of sulfuric acid

For storing manufactured 98 % H_2SO_4 there are two installed storage tanks, with contents of 500 m^3 for each. For dispatch of the acid are used tank, pump, head tank, and fillers. Acid can be directed straight to fillers or to head tank from which it is distributed to containers.

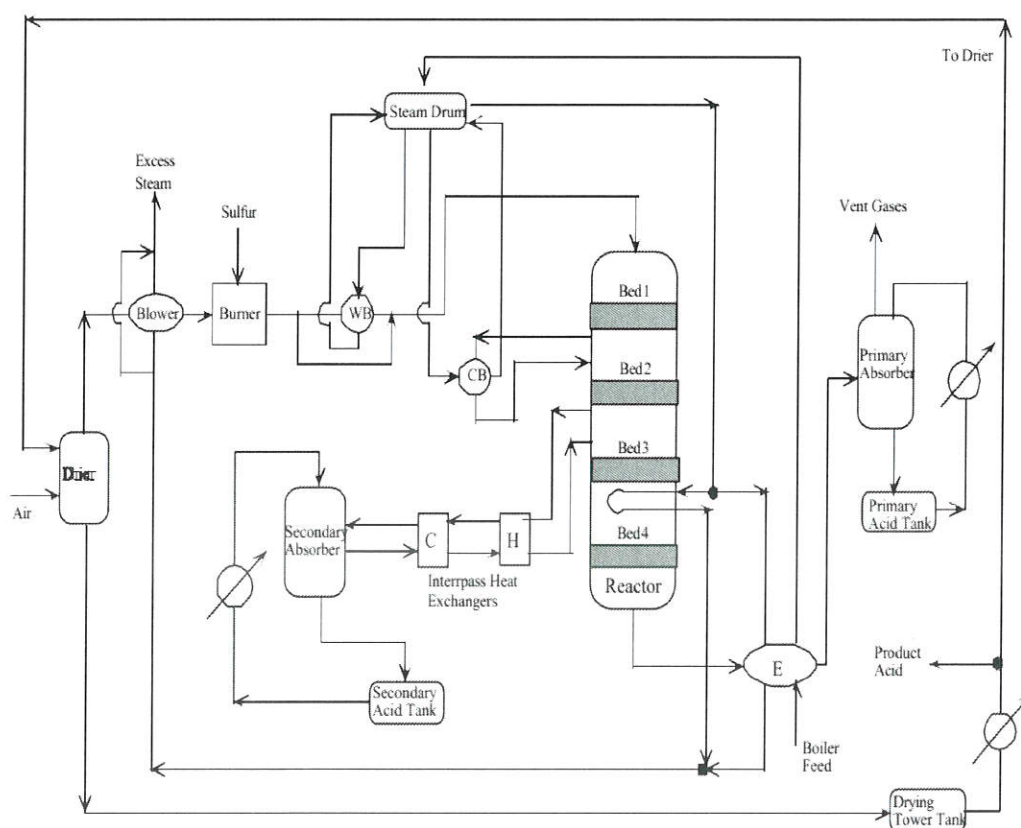


Figure 3-3 Sulfuric acid process flow map

Battery grade acid, owing to the required purity, may be delivered directly to head tank or fillers with omission of storage tanks.

3.2.2. Aluminium sulphate plant

3.2.2.1. Kaolin, weighing, charging and water suspension preparation.

Kaolin is loaded to charging bin with the help of loader and charged into suspension preparation tank with the weight of 6160 kg and 14.11 % of kaolin. Water-kaolin suspension is prepared by the addition of process water or filter-II will be 8904 kg in suspension preparation tank and thoroughly mixed.



3.2.2.2. Leaching or substitution reaction

Water-Kaolin suspension 15116.64 kg with 5573.6 kg of sulfuric acid mixed with 953.8 kg of steam is directly injected to maintain the required parameters (145 to 150 °C) and (0.45 to 0.5 MPa) in the reactors. Charging of reactants is based on the stoichiometric amount of the reaction. Moreover, lab analysis is performed for moisture content.

3.2.2.3. Neutralization reaction and laboratory analysis

The unreacted acid neutralized by the addition of 900 kg of water-aluminum hydroxide suspension which is prepared in suspension tank and transferred into adjustment tank accompanied with 100 kg of steam injection in order to pressurize the prepared suspension during charging it into the reactor(s).

Post reaction suspension (PRS) of 22946.075 kg sample is sent to quality control service lab for analysis to check concentration of total oxide, free oxide, or free acid in the sample, and its density. The analyzed post reaction suspension is 23691.49 kg. The adjustment parameters in the post reaction suspension tank the required amount of dilution water is calculated and added into post reaction suspension tank, acid is added to filtrate-I there is excess free oxide in post reaction suspension, however, if it contains excess acid it will be mixed with the next batch of elevated free oxide and the temperature is below 80 °C.

3.2.2.4. Filtration and laboratory analysis

Post reaction suspension is filtrated with the amount of 7475 kg, and the filter cake 5590 kg is backwashed with hot process water 5000 kg, and dried with compressed air to remove (scrap) and dispose the filter cake to stockyard.

Filter-I sample (6500 kg) sent to quality control service laboratory for analysis to check concentration of total oxide, free oxide or free acid in the sample, and its density. According to result of laboratory analysis either the next batch is made to be acidic or basic if the sample contains high free acid/oxide or filtrate-I is pumped into post reaction suspension tank if turbidity of the sample is above the permissible range or hydroxide is added in to the evaporator A or B if the sample contains low free acid.

3.2.2.5. Evaporation and crystallization

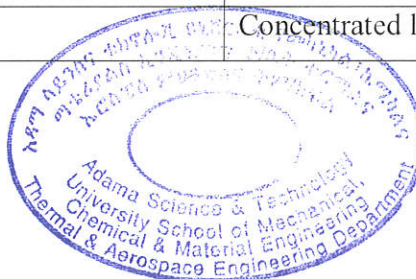
Level of filtrate-I in tank A or B is measured, pumped into evaporator A or B and steam is injected indirectly, the slurry is concentrated till the temperature reaches 110 to 113 °C. Trays are prepared for use, and the slurry is drained onto the trays, and left for 9 to 10 hours for scraped and transported for crushing with a loader after it has been crystallized.

3.2.2.6. Crushing, milling, packing and storage

Daily laborers reduce the size of lump aluminium manually. Manually crushed lump aluminium is further crushed, milled, packed, weighed and stitched in 50 kg bags. Finished product is issued to the finished goods store keeper and handled to store.

Table 3-2 Input and output process of aluminium sulphate

No	Input	Processes	Output
1	Kaolin=6160 kg Moisture=14.11%	Kaolin loading	Kaolin=6160 kg Moisture=14.11%
2	Kaolin=6160 kg Moisture=14.11%	Kaolin weighing	Weighted kaolin=6160 kg Moisture=14.11 %
3	Kaolin=6160 kg Process water=8904 liter	Suspension preparation	PRS in tank=22946 kg
4	Suspension=15116.64 kg Sulfuric acid=5573 kg Steam=953.8 liter	Reaction or leaching	Neutralized PRS=23691 kg
5	PRS=22946 kg Hydroxide suspension=900 kg, Steam=100 liter	Neutralization	Analyzed PRS=23691 kg
		Al(OH) ₃ suspension	
6	Neutralized PRS=23691 kg	Lab analysis	Adjusted PRS=23811 kg
7	Analyzed PRS=23691 kg Acid=99.8 kg Process water=2500 liter	Filtration	Filtrate-I=6500 kg Filtrate-II (A)=0.75 m ³ Filtrate-II (B)=3 m ³ Cake=5590 kg
8	Adjusted PRS=10444 kg Hot process water=5000 liter	Lab analysis	
9	Filtrate=7475kg	Evaporation	Analyzed filtrate=7475 kg
10	Analyzed filtrate=1913 kg Total oxide=8.36% Density=1.3 kg/liter	Crystallization	
11	Concentrated liquor=9696kg		Concentrated liquor=9696 kg



12	Lump aluminium=5633 kg/h		Lump hydrated aluminium=9657kg
13	Manually crushed=2916kg/h	Manual crushing	Crushed aluminium=5633 kg/h
14	Ground and packed aluminium=2916 kg/h	Finished product store	Packed aluminium=2916kg/h Product=350 kg/h

Process of production of the hydrated aluminum sulphate consists of leaching the aluminum oxide from Kaolin by means of sulfuric acid in the conditions of increased temperature and pressure. As a result of application of consecutive operations such as filtration of reactive suspension, filtrate concentration, and its solidification granulation a product containing 17 % Al_2O_3 is converted. As a result size reduction of less than 2.5 mm is obtained. The Kaolin is given by loader from the store into the bunker and it is transported by means of the bucket conveyer to the agitator of water and Kaolin suspension in the amount covering the needs of charging production. The kaolin is mixed in the agitator by means of mixer with water from washing the filter-cake delivered by the pump from the tank. The aim is to achieve 40% suspension of solid body in the liquid. The suspension prepared in such way is given gravitationally to the one of two working reactors. 98% sulfuric acid is led into the reactor from the buffer tank through the measurement tank.

In the reactor in the temperature of 150 °C and under the pressure of 0.4 MPa process of aluminum oxide leaching from kaolin and other metals oxides are occurs. 90 % efficiency of this process is achieved after four hours. Then the acid that has not reacted yet is neutralized in the reactor through two hours by means of aluminum hydroxide which is brought in form of water suspension by means of water pumping. As result of leaching and neutralization process a suspension is gained which is a mixture of silica, kaolin that has not reacted and aluminum hydroxide in the solution of aluminum sulphate and other metal sulphates. The mixture gets out from the reactor under its own pressure which is helped by the pressure of saturated steam of 0.4 MPa towards the end of the reactor emptying. It is emptied into one of three tanks.

The suspension is diluted to 7.5 % of Al_2O_3 converted by the water from washing the filter-cake led in by the pump from the tank and then it is transmitted by the pump to one of the filter-presses to separate solid body from the water solution of aluminum sulphate.

The filtrate from the press is directed to the filtrate tank and from there it is taken continuously by the pump to evaporator, in order to concentrate it up to concentration of 17 % as converted to Al_2O_3 . Washing of the filter-cake is carried out in the filter-presses using

hot process water heated in the heat exchanger to obtain a high degree of washing aluminum sulphate out of filter-cake. Filter-cake from filter processes is withdrawn with the help of conveyors on to temporary store wherefrom by tippers it is removed outside the plant. Dilute filtrate is directed via heating column to filtrate tank, wherefrom by pump is periodically removed to post reaction suspension tank and mixer.

Vapors evolved from evaporator partly used in heat exchanger for heating water and removed to stack. Concentrated solution is removed from evaporator to band crystallizer to solidify it. Solidified and pre crushed aluminum sulphate is handled with conveyor to bulk aluminum sulphate store. After seasoning the pre-crushed aluminum sulphate is loaded by loader to bin (hoper), wherefrom it is transported with conveyor to mill where it is ground down to 0-2.5 mm sized grain. Such ground sulphate is fed with conveyor and to bin (hoper). From Bin aluminum sulphate is sent to packaging equipment and packs sulphate to bags and seam or glue the bags. The bagged aluminum sulphate is placed on pallets and, by means of fork-lift truck, handled to store. The system of milling, handling and packaging aluminum sulphate has a de-dusting unit composed of cyclone, washer, exhaust fan; washer effluent is returned to the process.

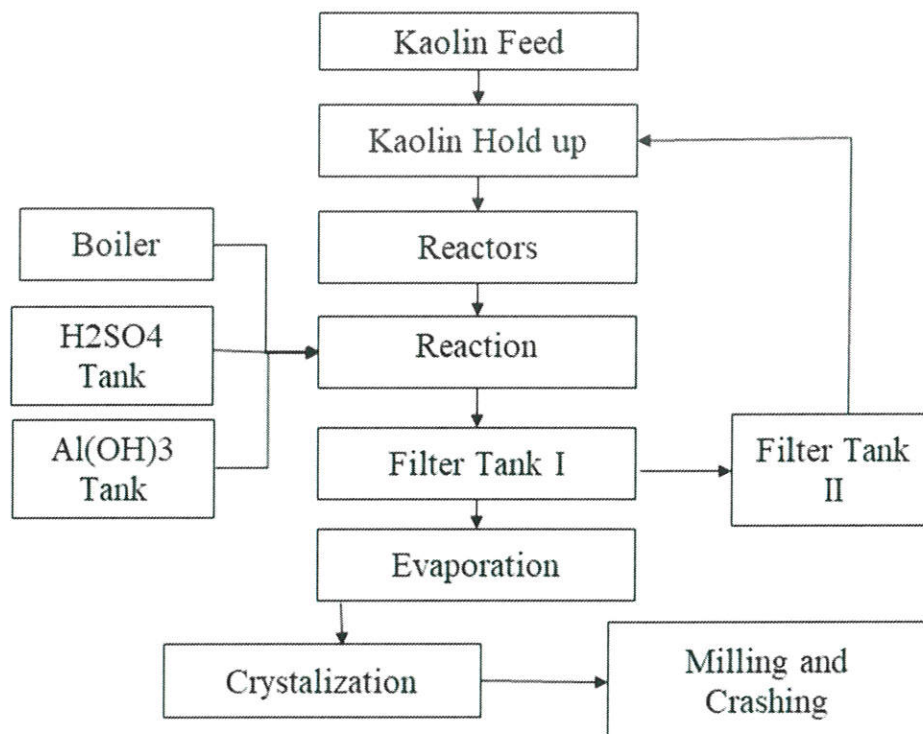
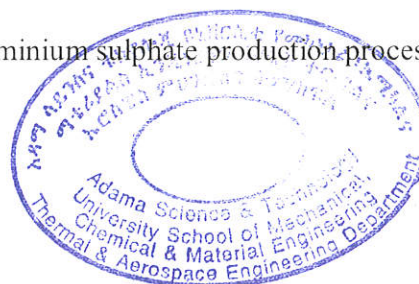


Figure 3-4 Aluminium sulphate production process



3.3. Description of the auxiliary system

3.3.1. Power system

The power system consists of two boilers, one of which being waste heat boiler for utilization of the heat of sulfur combustion and SO_2 oxidization. It generates saturated steam with pressure 2.128 MPa. The second type of boiler is fired with fuel oil. It generates saturated steam with pressure 1.32 MPa, which on reducing down to 0.608 MPa and cooling down to 165°C in reducing and cooling station is partly used for internal needs of boiler unit, and the rest is directed for the needs of the SAP and ASP process.

The boilers are fed with demineralized water and condensate from SAP and ASP process. Heated water in preheater is directed to deaerator wherefrom it is delivered with pump to waste heat boiler via economizer and fired with fuel oil boiler. Return condensate is collected in tank wherefrom it is periodically supplied to deaerator with pump. The boilers are blown down in continuous manner. The blow down water is tapped to the expander from which steam with 0.303 MPa pressure is tapped to the deaerator. The remaining blow down water is cooled down in the cooler where after cooling with water down to the temperature of 40°C it is drained to the gutter.

To correct the boiler water there is used tri-sodium phosphate solution prepared in the phosphate tank. The pump to the deaerator meters phosphate solution.

3.3.2. Water demineralization system

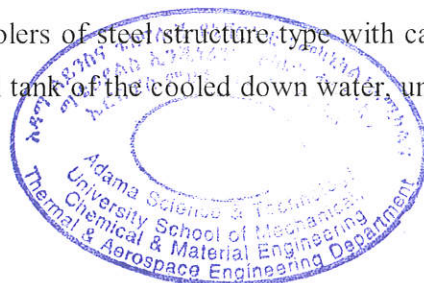
Demineralized water requirement for the power system and for production of sulfuric battery acid is maximum $Q=5\text{ m}^3/\text{h}$.

The river water is being filtered and gas free will be conveyed into the demineralized water station. Water hardness will be maximum $0.02\text{ mg}/\text{dm}^3$ and iron content maximum $0.05\text{ mg}/\text{dm}^3$. The iron remover has been applied because of possibility of existence of big amounts of iron in the river water, which can be $2\text{--}19\text{ mg}/\text{dm}^3$.

The demineralized water will be sent into the storage tank having capacity of 42.5 m^3 while ensuring six hours work of the plant.

3.3.3. Cooling Water System

Cooling feed water requirement is $200\text{ m}^3/\text{h}$ while keeping water heating in the receivers by 7°C and while the return water temperature does not exceed 34°C . The cooling water system is equipped with two fan coolers of steel structure type with capacity of $120\text{ m}^3/\text{h}$ each. The cooler consists of the steel tank of the cooled down water, unit of heat exchange



and set of three fans. All these are placed on the foundation of a frame form. The cooled down water is pumped from the tank into the receivers by means of the pumps and it is supplied by pipe lines running along the trestle. Return water heated up to 34°C flows down gravitationally by underground pipelines to the terrestrial reservoir of heated water situated near the cooler and it is pumped up to the cooler upper part by means of the pumps. It is cooled down there to the temperature of 27°C while flowing down gravitationally through the unit of heat exchange in counter-current to the air sucked by the fans of the cooler.

3.3.4. Fuel oil system

The kinds of oil used by the factory are fuel oil and gas oil. The fuel oil used for firing of the boiler the amount of 112.5 liter per hour and for starting of the contact unit of the sulfuric acid plant. The gas oil used for driving of the diesel generator in the amount of 112.5 liter per hour when applying 100 % but most of the time the factory use its 85% that means 95.63 liter per hour.

3.3.5. Compressed air system

The compressed air system consists of two screw compressors, preliminary air filter, air drier, final air filter and tank for dried compressed air. The capacity of the installed is $220\text{ m}^3/\text{h}$. Compressed air pressure and dried air temperature is 0.7 MPa and 20°C respectively.

3.4. Electrical, Fuel and Water usage

3.4.1. Electricity

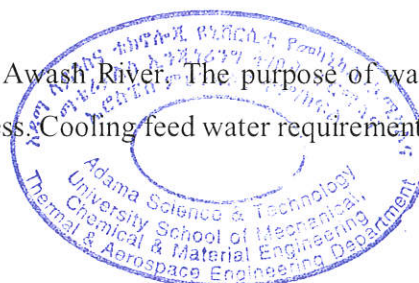
The company uses an average of 92,640 kWh per month from the grid, it divided in two to lines for aluminium sulphate, and sulfuric acid.

3.4.2. Fuel

The company uses boiler to produce steam for the production process of sulfuric acid and aluminum sulphate. The major fuel supplier of the factory is National Oil Company (NOC). The factory purchases an average of 2000 m^3 of furnace oil per annual from its supplier. The main use of this furnace oil is for producing steam in the boiler.

3.4.3. Water

Input of water for the company is from Awash River. The purpose of water is for the production of steam for the production process. Cooling feed water requirement is $200\text{ m}^3/\text{h}$.



The cooling water system is equipped with two fan coolers of steel structure type with capacity of 120 m³/h each.

3.4.4. Organizational structure

3.5.4.1 Staff profile and operating hours

Number of employees of the factory is 295 permanent and 45 temporary with 340 and the detail description is indicated in the Table 3.3.

Table 3-3 Staff profile and operating hours

Employees		Shift	Employee/shift	Hour/shift
Permanent	295	1 st	45-50	8hr
Temporary	45	2 nd	45-51	8hr
Total	340	3 rd	45-52	8hr
		4 th	45-53	Supporter

3.4.5. Organizational structures of the company

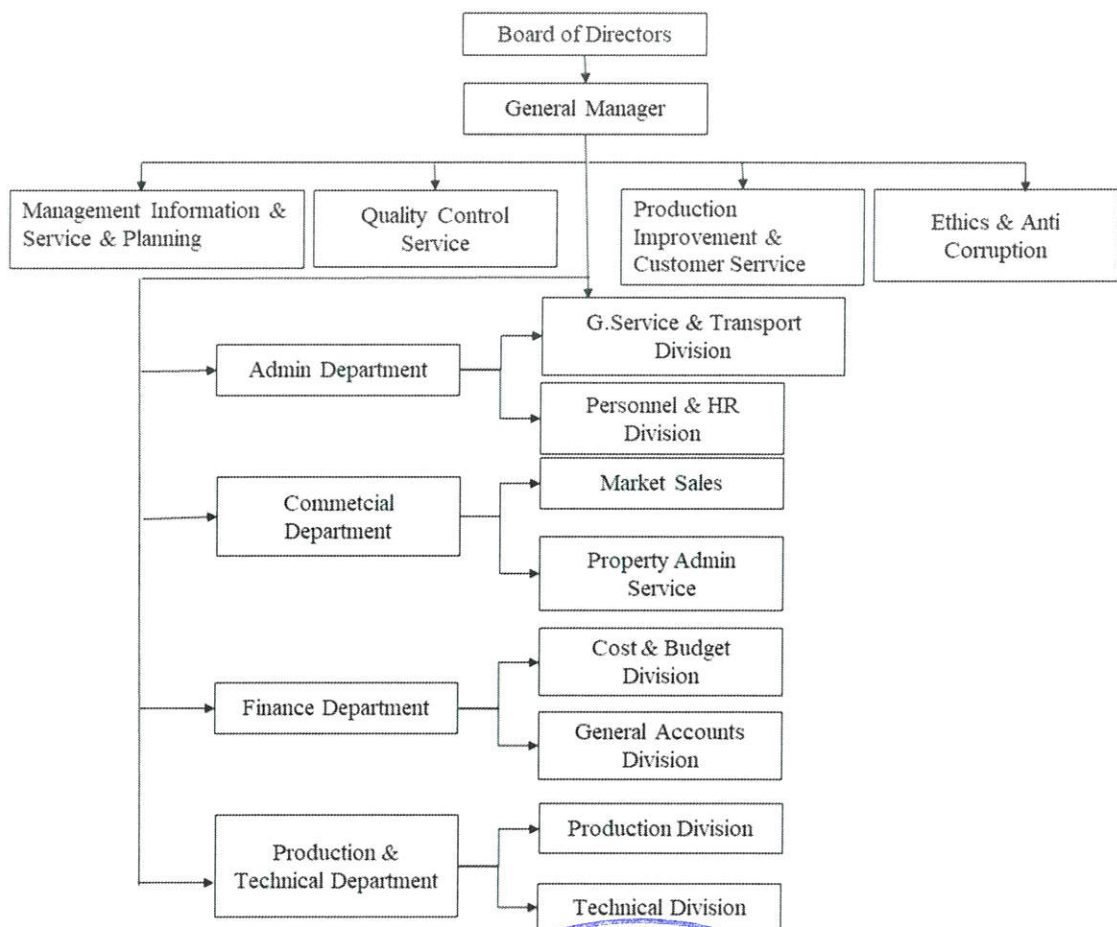
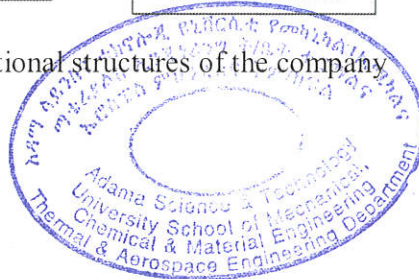


Figure 3-5 Organizational structures of the company



CHAPTER FOUR

4. ENERGY UTILIZATION OF AMASSASC

4.1. INTRODUCTION

AMASSASC uses both electric and thermal energy for the production of sulfuric acid and aluminum sulphate. The company pays the cost for both electric and thermal energy. The thermal energy is used for full production and the electrical energy is used for process and driving other devices. For the years of 2005- 2009 E.C the amount of energy consumed by the process and amount of fuel consumed are describe below. [2]

Table 4-1 Production and consumption of electricity and fuel (2005-2009) EC

Production and Consumption (2005-2009) EC			
Year	Production (ton)	Electric Consumption (kWh)	Fuel consumption (liter)
2005	7,176.45	1,063,051.84	415,657.0
2006	8,231.30	1,099,307.40	521,560.0
2007	11,381.00	1,217,500.00	573,131.1
2008	11,608.00	1,719,500.00	396,210.0
2009	7,670.10	773,750.00	415,654.0
Total	46066.853	5873109.244	2322212.07

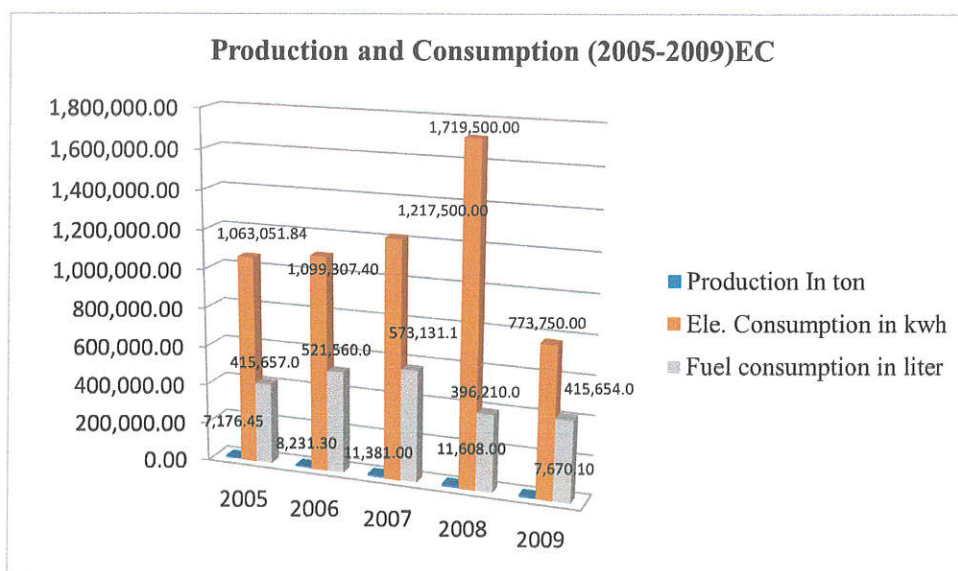


Figure 4-1 Production and consumption (2005-2009) EC



The designed capacity of production of sulfuric acid per ton is 85 kWh and designed capacity of aluminum sulphate production per ton is 92 kWh but in the year of 2009 EC the consumption for both production lines are 1,132,000 kWh to produce 7670.103 ton of aluminum sulphate and sulfuric acid.

That means

$$\text{Consumption of aluminium sulphate/ton (kWh)} = \frac{1 \text{ ton} \times 572827.55 \text{ kWh}}{3881.313 \text{ ton}} = 147.586 \text{ kWh}$$

$$\text{Consumption of sulfuric acid/ton (kWh)} = \frac{1 \text{ ton} \times 559172.449 \text{ kWh}}{3788.79 \text{ ton}} = 147.5 \text{ kWh}$$

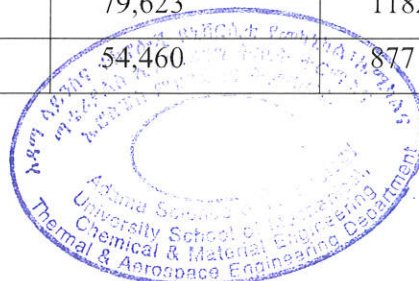
4.2. Energy consumption of the factory

The factory consumes both furnace oil and electricity in order to operate its major energy consuming systems. For example, electricity is consumed to operate motor, pumps and fans in the plant and also to operate different machineries in the plant machine shop. A small amount of electricity is also used for lighting. In addition to electricity, the factory uses steam boiler to produce steam for the production of sulfuric acid and aluminum sulphate in order to achieve this process the factory consumes large amount of steam.

To analyze the factory's energy bill, the 12-month energy (furnace oil and electric), and sulfuric acid and aluminum sulphate data are collected from 12-month job implementation report. In addition to this, energy intensity data of factory (benchmark) are collected for assessment. These collected data are presented Table 4.2 [2].

Table 4-2 Monthly consumptions of electricity and fuel in 2009EC

Period of billing	Electricity consumption(kWh)	Fuel consumption (liter)	Sulfuric acid & aluminium sulphate production(ton)
Ju-2009	42,442	No production	No production
Aug-2009	44,704	No production	No production
Sep-2009	158,000	66,715	948
Oct-2009	23,590	57,033	1616
Nov-2009	203,336	82,836	1710
Dec-2009	81,694	43,461	1109
Jan-2009	20,238	Luck of raw material	Luck of raw material
Feb-2009	23,828	14,742	87
Mar-2009	73,598	79,623	1182
Apr-2009	56,066	54,460	877



May-2009	19,918	16,784	123
Jun-2009	26,336	No production	No production
Total	773,750	415,654	7670

4.3. Benchmarking

There is no clear data for these kinds of chemical industries but there is the designed electric consumption, global consumption and current consumption of the factory obtained from the process description catalogue and manual. This data is presented in Table 4.3.

Table 4-3 Benchmarking [2]

Process	Designed consumption (kWh)	Global consumption (kWh)	Current consumption (kWh)
Sulfuric acid	85	73	147.5
Aluminum sulphate	92	75	147.8

4.4. Energy cost of the factory

The prices for fuel energy are set by market condition, but within any geographical area they are fairly constant. Essentially, the price is simply a smooth change per liter, so the total cost is the number of liter used times the price per liter. The gross calorific value (GCV) and the specific gravity of furnace oil are $4.1868 \text{ kJ} \times 10500 \text{ kcal} = 43,961 \text{ kJ/kg}$ and 0.92 respectively. The price is taken as 16.5 Birr/liter according to Ethiopian Petroleum Agency price. Billing for electricity is varying according to voltage consumption and number of phases used in the factory. The factory use three phase and high voltage 15 kV line, so according to Ethiopia Electric Power Corporation (EEPC) the tariff is high voltage tariff with smooth multiplying factor of all consumed kWh is 0.55 Birr/kWh.

Electricity and furnace oil cost are given by

Electric cost = $0.55 \text{ Birr/kWh} \times \text{Electricity used by month (kWh)}$

Fuel cost = $16.5 \text{ Birr/Liter} \times \text{Furnace oil used by month (liter)}$

Using the data from the above Table 4.2 and substituting the values of monthly consumptions of electricity and furnace oil. The result obtained is presented in Table 4.4 with the total cost for both electricity and furnace oil.

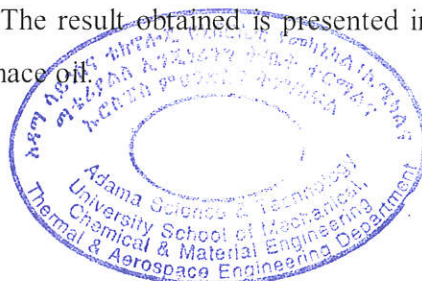


Table 4-4 Consumptions of electric and fuel (Birr)

Period of billing	Electricity consumption(Birr)	Fuel consumption (Birr)	Total cost (Birr)
Jul-2009	21,221	0	21,221
Aug-2009	22,352	0	22,352
Sep-2009	79,000	947,353	145,715
Oct-2009	11,795	809,868.6	68,828
Nov-2009	101,668	1,176,271.2	184,504
Dec-2009	40,847	617,146.2	84,308
Jan-2009	10,119	0	10,119
Feb-2009	11,914	209,336.4	26,656
Mar-2009	36,799	1,130,646.6	116,422
Apr-2009	28,033	773,332	82,493
May-2009	9,959	238,332.8	26,743
Jun-2009	13,168	0	13,168
Total	386,875	5,902,286.8	802,529

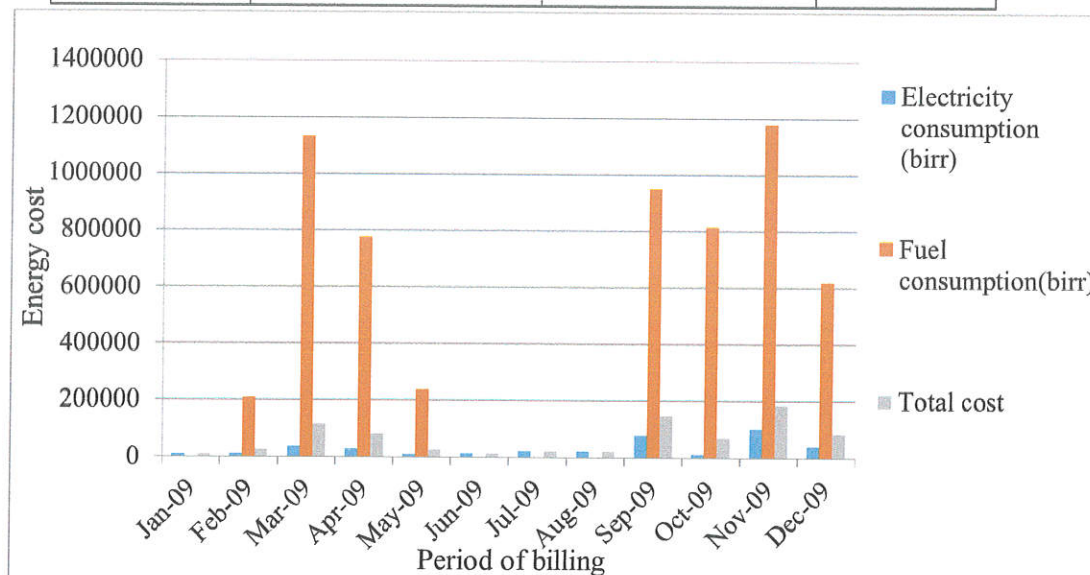


Figure 4-2 Monthly energy cost of the factory

4.5. Energy amount consumption of the factory

Monthly energy amount consumption is defined as an average monthly energy needed to produce one ton of sulfuric acid and aluminum sulphate.

Electricity and furnace oil amount of consumption is given by the following equations.



Electric energy consumption

Electric energy amount of consumption

$$= [\text{monthly electric used (kWh)} * 3600 \text{ sec}] / \text{monthly production} \dots \dots \dots (4.1)$$

We can take one sample from Table 4.2 (Sep-2009)

Electric energy amount of consumption

$$= [158,000 \text{ kWh} * 3600 \text{ sec}] / 948 \text{ ton}$$

$$= 600,000 \text{ kJ/ton.}$$

Furnace oil energy consumption

Furnace oil energy consumption

$$= [\text{GCV} * \rho_{\text{fuel}} * \text{monthly fuel used (liter)}] / \text{monthly production} \dots \dots \dots (4.2)$$

Electric energy amount of consumption

$$= [43,961 \text{ kJ/kg} * 0.92 \text{ kg/liter} * 66,715 \text{ liter}] / 948 \text{ ton}$$

$$= 2,841,636.8 \text{ kJ/ton}$$

Using data from Table 4.4 and insert in equation 4.1 and 4.2 in order to get monthly consumption of electricity and furnace oil. The result of this calculation is presented in Table 4.5.

Table 4-5 Energy amount of consumption (kJ)

Period of billing	Furnace oil energy amount of consumption(kJ/ton)	Electric energy amount of consumption(kJ/ton)
Jul-2009	0	-
Aug-09	0	-
Sep-09	2,841,636.753	600,000.00
Oct-09	1,425,076.795	52,551.98
Nov-09	1,956,034.08	428,075.79
Dec-09	1,582,419.321	265,192.43
Jan-09	0	-
Feb-09	6,842,118.041	985,986.21
Mar-09	2,720,034.85	224,156.35
Apr-09	2,507,445.209	230,145.50
May-09	5,509,900.644	582,965.85
Jun-09	0	



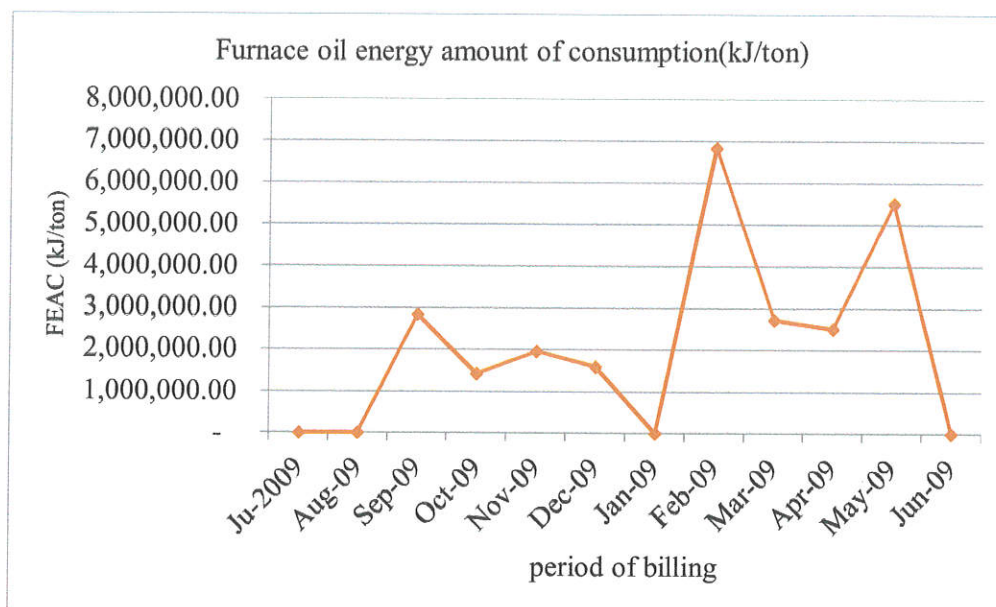


Figure 4-3 Furnace oil amount of consumption (kJ)

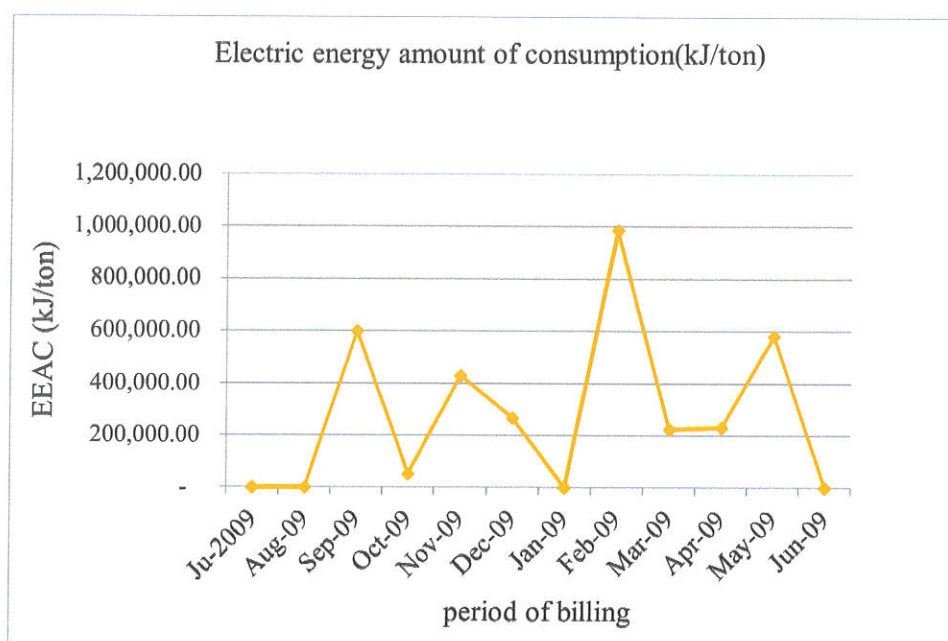
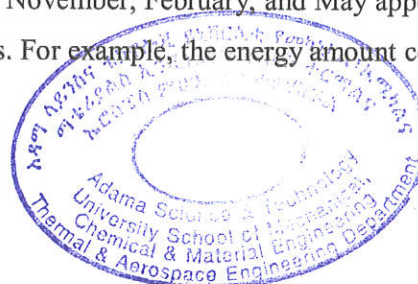


Figure 4-4 Amount of electric energy consumed (kJ)

4.6. Investigation of the energy utilization of the factory

As is clearly seen in Figure 4.2 and 4.3 the energy consumption pattern of the factory considerably varies over the whole financial year, 2009 E.C. Both fuel and electric energy amount during the months of September, November, February, and May appear to increase significantly as compared to other months. For example, the energy amount consumption of



the month of September is greater than the month of October by 547,448 kJ/ton of electric energy and 1,416,559.96 kJ/ton for fuel energy. The reason for increasing energy consumption amount during month of September is idle running time for energy consuming machines due to shortage of Kaolin and Sulfur (raw materials), the production of both Sulfuric acid and Aluminum Sulphate is decreased. In addition, Figure 4.2 (fuel) clearly show that the fuel energy consumption is slightly varies from month to month. These deviations indicate that the energy efficiency of the boiler with time has decreased. Thus the boiler is one of the main energy consuming systems of the factory that must be studied carefully.

4.7. Energy consumption amount comparison of factory with benchmark

The comparison is done between energy consumption of Awash Melkassa Aluminum Sulphate and Sulfuric Acid Share Company (AMASSASCo) and the benchmark Table 4.3. From the analysis of the energy consumption of the AMASSASCo, it can be seen that there is a significant difference between the energy consumption of the AMASSASCo as compared to the benchmark.

The 12-month fuel energy intensity of AMASSASCo ranges from 1,425,076.7 – 6,842,118 kJ/ton of sulfuric acid and aluminum sulphate with monthly average energy intensity of 4,133,597 kJ/ton of sulfuric acid and aluminum sulphate. The energy intensity of benchmark, for example shown in Figure 4.3 gives monthly average energy intensity of 22,298.55 kJ/ton of sulfuric acid and aluminum sulphate. Hence, a difference of 8598.9kJ/ton exists between the average practice of the benchmark and what exists at AMASSASCo.

The electricity energy intensity of AMASSASCo in the 12-months ranges between 52,551.9 to 985,986.2 kJ/ton of sulfuric acid and aluminum sulphate with an average intensity of 519,269 kJ/ton of sulfuric acid and aluminum sulphate. The energy intensity of the benchmark, for example showed in Figure 4.3 gives an average energy intensity of 518,400 kJ/ton of sulfuric acid and aluminum sulphate. Hence a difference of 869 kJ/ton exists between the average practice of a benchmark and what exists at AMASSASCo.

4.8. Concluding remark on the energy intensity comparison

Based on the above analysis, the AMASSASCo energy utilization system is seen to be in efficient and more costly as compared to the benchmark. This is mainly due to energy mismanagement and lack of attention to energy wastage during low production season. The

losses suffered by the factory greatly reduce its profits. Thus, the factory must conduct energy audit on its major energy systems.

4.9. Preliminary energy audit and its energy conservation [3]

4.9.1. Introduction

The preliminary energy audit of the factory is performed through inspection of the nine general energy systems:

- 1- The building envelop,
- 2- Boiler and steam distribution systems,
- 3- The heating ventilating and air conditioning systems (HVAC)
- 4- The electric supply systems
- 5- The lighting systems
- 6- Hot water distribution systems
- 7- The compressed air distribution systems
- 8- The motor and
- 9- Production process systems

Using visual inspection, common sense and interview with factory workers in order to identify energy conservation opportunities and identify the major energy systems of the factory to perform the detail energy audit of the major systems. From the above nine general energy systems the following systems are selected to be discussed.

- Inspection of Boiler and Steam Distribution Systems
- Inspection of compressed air distribution systems
- Inspection of Motors
- Inspection of Production Process

4.9.2. Assessment of boiler and steam distribution systems

The boiler used in the factory is manufactured by an Italian company, with three-pass fire tube design (Figure 4.5). The systems includes in the boiler are; feed water system, steam system and fuel system. In addition to these main systems, the boiler has deaerator and water treatment plant. The feed water system provides water to the boiler and regulates it automatically to produce the specified capacity of steam in the boiler. There is no condensate return because the steam is used as feed steam. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the different points of use. Throughout the system, steam

pressure is regulated using manual valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the heat. The boiler uses furnace oil.

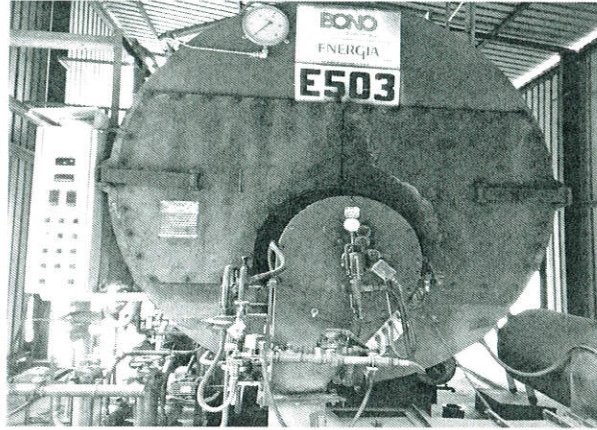


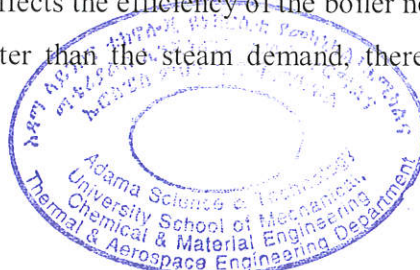
Figure 4-5 Factory boiler

4.9.3. Identification of energy conservation opportunity

Inspection of the boiler and steam distribution system is conducted using visual inspection common sense and interview with factory workers and these revealed the following energy conservation opportunities.

The various energy efficiency opportunities in boiler and steam distribution line systems can be related to combustion, heat transfer, avoidable losses, water quality and blow down. These are inspected and the following lists of energy conservation opportunities are mentioned.

- No periodic soot blowing of the boiler is done,
- No periodic scale removing of the boiler waterside,
- Steam traps are not checked for proper functioning regularly,
- The boiler is very dirty,
- Some steam pipes are not insulated very well,
- The boiler is without an economizer (it is very old).
- The water treatment plant is not good due to the failure of some component of the plant.
- The carbon dioxide content of the flue gases of the boiler is much more below the recommended value, which affects the efficiency of the boiler negatively.
- The steam produced is greater than the steam demand, therefore the boiler is oversized



The identification from above 5 bullets is simple to be implemented with the routine maintenance program of the factory with no or low cost. But, the rest identifications need to further data collection and requires conducting detail energy audit of the boiler.

4.9.4. Assessment of the compressed air distribution system

The factory used piston type double stage and water-cooled compressor. The inspection of compressor and compressed air distribution system is conducted using visual inspection.

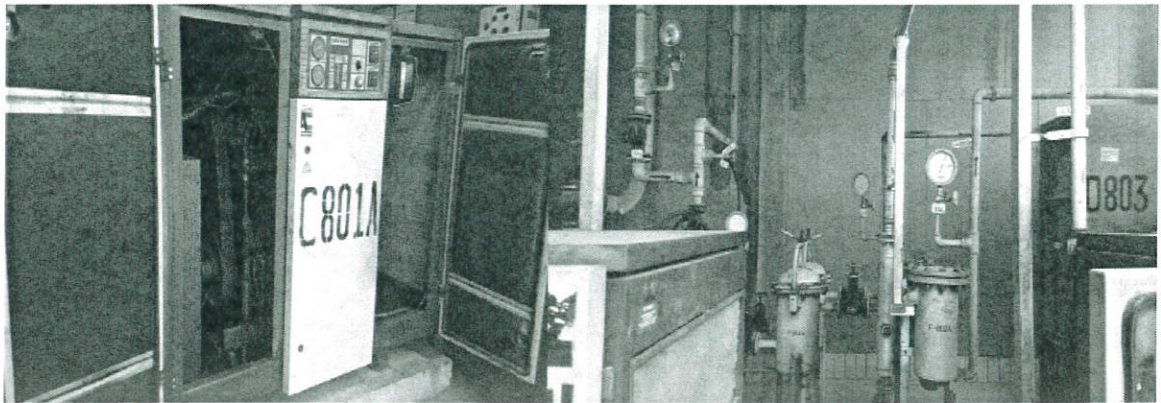


Figure 4-6 Factory compressor

The factory is air compressor, compressed air distribution systems are used open, and closes through different production process in the factory, operate pneumatic valve and dust remover. The compressed air distribution system has no leak and the compressor is placed properly but mostly the dust collector valve is resided open for long time after completing its task.

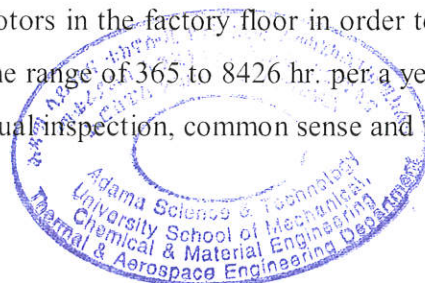
4.9.5. Identification of energy conservation opportunity

There is no systematic control of compressed air distribution valves.

The energy conservation opportunity can be handled by any assigned shift technician to shut off the valve when unneeded compressed is not needed air or delay the supply of compressed air until needed. Therefore, controlling compressed air distribution valve require no cost energy conservation opportunity that can be handled with the routine job of the factory.

4.9.6. Assessment of the motor systems

There are over 12 three phase motors in the factory floor in order to move pumps, fans and air compressor that operate in the range of 365 to 8426 hr. per a year. Inspection of the motor system is conducted using visual inspection, common sense and interview made with



electrical maintenance personnel and these revealed the following energy conservation opportunities.

4.9.7. Identification of energy conservation opportunity

The various energy efficiency opportunities in motor systems can be related to efficiency, power factor are inspected, and the following energy saving opportunities are discovered.

- Most of the electric motors are exposed to dirt,
- Most of the motors are old (installed when the factory built),
- The nameplate power factor ranges from 0.82 to 0.88 %.
- Nameplate efficiency of the motors ranges 0.80 to 0.86 %

The first energy conservation opportunity from the above is simple to be implementing with the repetitive maintenance program of the factory with no cost. But the rest points of energy conservation opportunity from the above needs to further data collection and requires conducting detail energy audit of the motors with their prime movers.

4.9.8. Assessment of the production process

The production systems of the factory intensively utilized thermal and electric energy. The production process consumes all the thermal energy. The electric energy mainly drives pumps, air compressor and fans. Melting of sulfur is one of the most energy intensive operations in the factory. It is used throughout sulfuric acid producing processes to keep it as a molten state and other process. The incoming flow is heated, after which the products are separated based on boiling points. The steam provides the heat needed for the sulfur.

Inspection of production system means inspection of sulfuric acid plant because it consumes almost all-thermal energy produced by the boiler. Hence inspection of the motor system is conducted using visual inspection, common sense and interview made with factory personnel and these revealed the following energy conservation opportunities.



Figure 4-7 Factory process systems

4.9.8.1. Identification of energy conservation opportunity

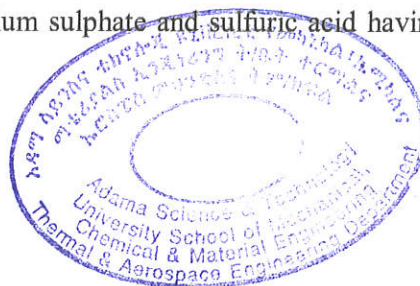
The production systems of the factory were assessed for potential energy saving opportunity and the following were obtained.

- Everyday production interruption due to leakage and insulations problem.
- For long time the measuring instruments such as pressure sensing and flow rate measuring system were not calibrated and cleaned.
- The steam lines are old and not insulated well.
- Large quantity of steam is vent just before arriving to end uses.
- Large amount of condensate water leaked.

Energy saving opportunities from the first 3 bullet is technically possible. Energy saving opportunity is low cost or no cost that can be handled with the repetitive maintenance and job of the factory. The rest energy saving opportunities requires further data collection on vent steam and it will be appropriate to discuss it on detail energy audit.

4.9.9. Identification of the major energy systems of the factory

As is clearly discussed in the preceding chapters there are so many equipment's that are engaged in the production of aluminium sulphate and sulfuric acid having direct relation



with energy consumption or development in the factory. From production process, the preliminary audit result and, interview made with factory workers the major energy systems of the factory are found to be:

- Boiler and steam distribution systems
- Compressed air system, and
- Electric motors and their prime movers

Moreover, of the total energy production from furnace oil, almost all goes to the production processes. Moreover, the total energy supplied from electric power, almost 90%, goes to motors. Saving energy in the factory would then become a question of improving combustion efficiency of the boiler and a better use of energy that is exhausted through existing processes and improving motors' efficiency and a better use of energy in its prime movers. Therefore, the detail energy audit of these major energy systems of the factory were performed through assessment of their energy performance in chapter 5 and 6, respectively.



CHAPTER FIVE

5. DETAIL ENERGY AUDIT OF THE BOILER

5.1. Introduction

The type of boiler used by the factory is SM/FB 600/15/N fire tube steam-generator (boiler) and an Italian company (BONO ENERGIA SPA) in 2003 manufactures it. Its main function is to supply superheated steam to the production process of the factory. While the boiler performs its function, it consumes a large amount of fuel. So, relatively small efficiency improvement in the boiler plant can produce greater overall energy saving than much larger efficiency improvements in individual end use devices of the factory. This reason makes the boiler plant, as a good place to start searching for energy saving opportunities to take the correct energy conservation measures.

5.2. Boiler data collection

The boiler used by the factory has the specifications indicated in Table 5.1 [2].

Table 5-1 Factory boiler specification

	Specifications	Method of data collection
Type	Fire tube	Catalogue
Model	SM/FB 600/15/N	>>
Boiler rated capacity (TPH)	6	>>
Actual steam generation (TPH)	4.3	>>
Rated design pressure (bar)	15	>>
Test pressure (bar)	14.7	>>
Actual steam generation pressure	12.5	>>
Actual steam generation temperature (°C)	187.4	>>
Feed water temperature (°C)	80	>>
Blow down (automatic) liter/min	0.697	>>
Efficiency (%)	Net 93.3, gross 86.93	>>
Local ambient temperature (°C)	27	>>
Average boiler surface temperature (°C)	40	>>
Diameter (m)	3	>>

Length (m)	4	>>
Total surface area of the boiler exposed to ambient (m ²)	51.8	>>
Wind speed (m/sec)	0	>>
Fuel pre-heating temperature (°C)	85	>>
Fuel oil consumption (lit/hr)	440.2	>>

To perform the energy audits, energy balances and determine the efficiency of the boiler, the following data/measurements are required.

- Boiler dimension and surface temperature
- Feed water flow rate and temperature
- Boiler steam pressure, temperature and flow rate
- Combustion air temperature
- Ambient temperature
- Fuel oil flow rate and pre-heating temperature
- Flue gas temperature and percentage of combustion products constituents, and
- Temperature and flow rate of the boiler blow down.

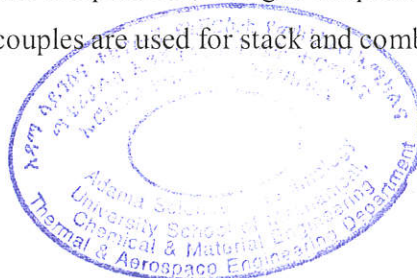
These different data related to steam generation and utilization of the boiler were collected by:

- Direct measurement using portable instruments
- Direct recording from factory boiler control panel
- Referring to different factory record book and log sheets, and
- Interview with factory workers.

Inspection of the boiler and steam distribution system was conducted using portable combustion analyzer (PCA), infrared and dual K contact thermometer, tape rule, ultrasonic flow meter (and also optionally using bucket and stop watch) and visual inspection.

5.2.1. Flue gas data

Portable Combustion Analyzer (PCA) was used to analyze combustion normally for tune-ups, maintenance and emissions monitoring. PCA has the capability of measuring, displaying, and storing combustion tests. It displays flue gas, oxygen content, carbon dioxide content, carbon monoxide content, air temperature, flue gas temperature, stack loss, and the fuel type to be monitored. Thermocouples are used for stack and combustion air temperature measurements.



A pressure transducer was used for the draft pressure measurement. An in-built computer performs the combustion calculations, and shows the results of constituents of gases and draft pressure. These data are presented in Table 5.2.

Table 5-2 Flue gas measured data

No	Element	Reading	Data collection
1	O ₂ in flue gas (%)	11	Measured
2	Flue gas CO ₂ (%)	7.8	>>
3	Flue gas CO (ppm)	9.8	>>
4	Ambient temperature (C ⁰)	27	>>
5	Stack temperature (C ⁰)	230	>>
6	Draft (WC)	0.4	>>
7	Combustion efficiency (%)	77.8	>>
8	Flue gas excess air (%)	17.9	>>
9	Dry flue gas loss (%)	12.9	>>
10	Wet flue gas loss (%)	4.47	>>
11	CO (%)	0.11	>>
12	Free stream air composition		
	Oxygen 21 %	Nitrogen 78 %	

5.2.2. Boiler surface data

Boiler surface is relatively hotter than the ambient air and are exposed to ambient air which is relatively cold. As a result, surface losses from the boiler will occur. To estimate the energy lost from the boiler surfaces, surface temperatures of the boiler that are exposed to the ambient are measured at different location using an infrared and dual K contact thermometer. The boiler is cylindrical in shape and the surfaces that are exposed to the ambient are; the cylindrical, and front and back surfaces. In addition to boiler surface temperatures, blow down, feed water and vent steam temperatures were measured. The averages of these measurements are listed in Table 5.3.



Table 5-3 Measured temperatures

No	Measured		
1	Blow down Temperature	115 °C	
2	Feed water Temperature	80 °C	
3	Vent Steam Temperature	127 °C	
4	Fuel Pre-heating Temperature	85 °C	
5	Ambient Temperature	27 °C	
6	Steam Produced	@ 187.4 °C & 13bar	
		Temperature(C°)	
		ambient	surface
7	Front Surface	33	106
8	Back surface	36	108
9	Cylindrical Surface	31	43

5.2.3. Boiler dimensions data

A Vernier's caliper was used to measure the internal pipe diameters of feed water pipe, blow down pipe, steam vent pipe and fuel oil pipe. An ordinary tape rule was used to measure the dimensions of the boiler. The diameters of each pipe are 0.03175 m, 0.03175 m, 0.02135 m and 0.0254 m.

$$A_{front} = A_{back} = \frac{\pi D^2}{4} \dots\dots\dots (5.1)$$

$$A_{cylindrical} = \pi DL \dots\dots\dots (5.2)$$

Total surface area of boiler exposed to ambient temperature is the summation of:

$$A_{total} = A_{front} + A_{back} + A_{cylindrical} \dots\dots\dots (5.3)$$

5.2.4. Boiler fluids flow velocity data

To facilitate the estimation of fluid flow through a pipe, ultra-sonic flow meter (bucket and stop watch) was used. Using this meter, the following flow velocities were measured: fuel flow velocity, blow down flow velocity, vent steam and feed water flow velocities are mentioned in Table 5.4.



Table 5-4 Measured velocities (m/s)

Items	Flow Type	Measured velocity (m/s)						
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
Blow down	Intermittent	0.112	0.115	0.112	0.113	0.111	0.114	0.1128
Vent Steam	Continuous	0.107	0.104	0.103	0.106	0.105	0.108	0.106
Feed Water	Continuous	0.6405	0.6404	0.6406	0.6402	0.6403	0.6405	0.6404
Fuel Oil	Continuous	0.0420	0.0422	0.04208	0.04209	0.04207	0.04206	0.04208

5.2.5. Furnace oil and composition data

According to reference [8], the chemical and physical composition and gross calorific values (GCV) of furnace oil are as shown in Table 5.5.

Table 5-5 Furnace oil and ultimate analysis (composition)

	Furnace oil composition	Ultimate Analysis (%)
1	Oxygen (O ₂)	0.5
2	Nitrogen (N ₂)	0.5
3	Hydrogen (H)	12
4	Carbon (C)	84
5	Sulfur (S)	1.5
6	Moisture (M)	0.5
7	Sp. gravity of oil	0.92
8	Gross Calorific Value = 43,961 kJ/kg	

5.2.6. Dry and wet air elements

Table 5-6 Dry and wet air elements (mass analysis)

Substance	wet air (a)	Dry air (b)	Molecular Mass (M)	Mass of Wet air $a \cdot M$	Mass of Dry air $b \cdot M$	Mass fraction of wet air $a \cdot M / 28.678$	Mole of substance in air per mole of O ₂
H ₂ O	0.01211	-	18	0.218	0	0.00899	0.0693
O ₂	0.2074	0.21	32	6.636	6.72	0.231	1
N ₂	0.7804	0.79	28	21.85	22.12	0.76	3.763
Total	0.999	1	78	28.704	28.84	0.99999	4.8323

5.2.7. Compounds and Their Molecular weight

The combustible elements in furnace oil are carbon, hydrogen and sulfur. During burning of furnace oil with dry air, these three elements give carbon dioxide, water and sulfur dioxide. Hence, the standard chemical reaction of furnace oil, when a kg of furnace oil is completely oxidized using dry air in to carbon dioxide, water vapor and sulfur dioxide, with inert nitrogen in the product is given by:

Table 5-7 Compounds and Their Molecular weight

Compound, Elements	Molecular Weight
C	12
O ₂	32
H ₂	2
S	32
N ₂	28
CO ₂	44
SO ₂	64
H ₂ O	18

5.3. Data analysis

5.3.1. Boiler dimension analysis

$$A_{front} = A_{back} = \frac{\pi D^2}{4} \dots \dots \dots (5.1)$$

$$A_{cylindrical} = \pi D L \dots \dots \dots (5.2)$$

5.3.2. Energy and mass balance analysis

So as to accomplish the detailed energy audit of the boiler the following pre-audit input-output energy and mass balance investigations are required.

- Heating value of furnace oil,
- Furnace oil combustion, and
- Mass flow rate of fuel
- Mass flow rate of feed water
- Mass flow rate of blow down and
- Mass flow rate of vent steam



5.3.3. Heating value of furnace oil

The net calorific value of furnace oil can be estimated by subtracting the total enthalpy of vaporization of water due to its hydrogen and moisture content. Using the following Equation the net calorific value of furnace oil can be estimated.

$$NCV = GCV - (M_{H_2O}) \times h_{fg} \dots \dots \dots (5.4)$$

Where

M_{H_2O} - Mass of water vapor in flue gas

h_{fg} - Enthalpy of vaporization of water = 2430.12 kJ/kg

M – Moisture content in furnace oil

$$M_{H_2O} = 9H (1-\%M) + \%M [8] \dots \dots \dots (5.5)$$

H is hydrogen mass in the furnace oil

5.3.4. Analysis of furnace oil combustion

To find the amount of energy liberated during furnace oil combustion, the analysis of mass and energy during combustion of the furnace oil, the combustion air and the combustion products are very important.

- Investigation of the elements of combustion air
- Air-fuel ratio of furnace oil burning
- Mass investigation of dry flue gases

5.3.4.1. Investigation of the Elements of Combustion Air

The ambient air used for combustion is composed of Oxygen (21 %) and Nitrogen (79 %) on dry basis [Table 5.2]. The actual air used for combustion is composed of moisture, oxygen and nitrogen at standard condition 27 °C and $P_a=1\text{ atm}$, the average relative humidity of the air used for combustion is $\phi = 53.25\%$ [7].

a) Absolute Humidity Factor ($A\gamma$)

The amount of moisture content of the air used for combustion can be found by calculating the absolute humidity or humidity factor of the air at the inlet temperature to the furnace, 27 °C. The humidity factor of the air is given by [3]

$$\text{Humidity factor } (\gamma_A) = 0.622 \frac{P_v}{P_o} \dots \dots \dots (5.5)$$

$$\text{Where } P_o = P_a - P_v \dots \dots \dots (5.6)$$

$$P_a = 101.325 \text{ kPa}$$

But the value of the partial pressure of the water,

$$P_v = \phi P_{sat@27^\circ\text{C}} = 53.25\% P_{sat} \dots \dots \dots (5.7)$$

From steam table @ 27°C the value of the saturation pressure, $P_{sat} = 4.502 \text{ kpa}$.

Hence

$$P_v = 53.25\% \times 4.502 \text{ kpa} = 2.397 \text{ kpa}$$

$$P_o = (101.325 - 2.397) \text{ kpa} = 98.928 \text{ kpa}.$$

b) Mass fraction of air elements relative to oxygen

To accomplish the actual chemical balance during burning of furnace oil with atmospheric air it is quite necessary to normalize mass fraction of the major air composition to handle the mass balance of the elements relative to oxygen and this procedure is discussed in Table 5.6.

5.3.4.2. Air fuel ratio of furnace oil burning

The theoretical and actual air fuel ratio of furnace oil burning on mass basis is important to determine the flow rate of flue gases.

5.3.4.2.1. Theoretical air-fuel ratio (TAR)

To determine the theoretical air-fuel ratio of burning furnace oil, a standard chemical reaction must be established which oxidizes 1kg of furnace oil completely into carbon dioxide and water with inert nitrogen in the product stream. The standard chemical reaction of furnace oil is the burning of 1kg of furnace oil using dry air [11]. The percentage of fuel elements is presented in Table 5.5.

$$\text{TAR} = \left[\frac{(11.6 \times C + 34.8 \left(H_2 - \frac{O_2}{8} + 4.35 \times S \right))}{100} \right] \text{ Kg/kg of furnace oil} \dots\dots\dots (5.8)$$

5.3.4.2.2. Actual air-fuel ratio of furnace oil (AA)

The actual mass of air used during burning of one kg of fuel in boiler furnace can be found from:-

$$\text{AAR} = \text{TAR} \times \left(1 + \frac{\text{EA}}{100} \right) \text{ Kg of air/kg of oil} \dots\dots\dots (5.10)$$

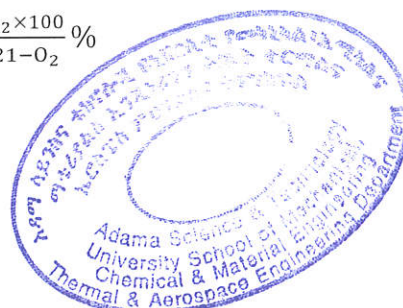
Where

TAR – Theoretical air fuel ratio

EA – Excess air supplied

However, Excess Air Supplied can be obtained by using equation 5.10:

$$\text{EA} = \frac{o_2 \times 100}{21 - O_2} \%$$



5.3.4.3. Mass flow rate analysis of dry flue gases

To determine the energy losses due to flue gases (stack loss), the mass flow rate of the flue gases must be found by using equation 5.11.

$$m_{fluegas} = m_{mass\ of\ flue\ gas} \frac{kg_{flue}}{kg_{fuel}} \times m_{fuel} \frac{kg_{fuel}}{sec} \dots\dots\dots (5.11)$$

To find out the mass flow rate of the dry flue gases the composition of the gas products of the actual chemical reaction in the boiler should be determined first.

1kg of furnace oil + Dry air, CO₂ + H₂O + SO₂ + N₂

Mathematically:-



5.3.5. Estimation of furnace combustion temperature

The combustion temperature of the furnace is important in the calculation of the energy loss due to dry flue gases. Due to the absence of furnace temperature sensing instrument in the boiler this temperature is not known. However, the combustion temperature prevailing in the furnace could be readily estimated from the moisture content and excess air used during combustion [8]. For 0.5 % moisture content of furnace oil, the furnace temperature at 110 % excess air was estimated to be 605.9 °C.

5.3.6. Specific heat of dry flue gases

For furnace oil the specific heat of dry flue gas is given by equation 5.13. [8]

$$C_{p_{fg}} = (0.3 + 0.000038T_{furnace}) \text{ Kcal/ kg}^0\text{C} \dots\dots\dots (5.13)$$

$T_{furnace}$ - Furnace temperature

$C_{p_{fg}}$ = Specific heat of dry flue gas

5.3.7. Analysis of mass flow rate of the boiler

In order to calculate the boiler input and output energy, the mass flow rate of: furnace oil, blow down, feed water and steam should be determined first.

5.3.7.1. Analysis of mass flow rate of furnace oil

Since the factory uses furnace oil as fuel source to generate steam, the mass flow rate of furnace oil, which is important to determine the input energy in to the boiler was determined by directly multiplying the measured fuel flow velocity, area of the fuel flow pipe and the density of fuel. Which are presented in Table 5.3.

$$m_f = V_f A_p \rho_f \dots\dots\dots (5.14)$$

Where

A_p – Area of fuel flow pipe

V_f – Velocity of fuel flow = 0.08208 m/s

ρ_f – Density of fuel = 991 kg/m³

D – Diameter of the pipe = 0.0254 m

5.3.7.2. Analysis of mass flow rate of feed water

Feed water is one of the major input sources of steam production. The mass flow rate of feed water is important to determine the input energy in to the boiler. The mass flow rate can be calculated by directly multiplying the measured feed water flow velocity, area of the pipe, feed water flow and the density of feed water presented in Table 5.3.

$$m_{fw} = V_{fw} A_{fw} \rho_{fw} \dots\dots\dots (5.15)$$

Where

V_{fw} – Velocity of feed water flow = 0.6404 m/sec

ρ_{fw} – Density of water = 1000 kg/m³

$$A_{fw} - \text{Pipe flow area} = \frac{\pi D^2}{4} = \frac{\pi (0.03175)^2}{4} = 0.000791 \text{ m}^2$$

5.3.7.3. Analysis of Mass Flow Rate of Blow down

Boiler blow down is one of the major causes of energy loss from boiler drum. In the factory, blow down is done manually by operating a valve fitted to a discharge pipe at the lowest point of the boiler shell. Blow down is done to reduce total dissolved solids (TDS). It is done by opening a 0.03175 m diameter line twice a shift for 10 minutes. The measured velocity, pipe diameter and density are presented in Table 5.3. The mass flow rate of blow down and pipe flow area can be obtained using the following equation.

$$m_{bd} = V_{bd} A_{bd} \rho_{bd} \dots\dots\dots (5.16)$$

Where

V_{bd} – Velocity of blow down flow = 0.1128 m/sec

ρ_{bd} – Density of blow down = 951 kg/m³ [5]

Therefore, it is possible to determine the blow down flow rate

$$A_{\text{pipe}} = \frac{\pi D^2}{4} = \frac{\pi (0.03175)^2}{4} = 0.000791 \text{ m}^2$$



5.3.7.4. Analysis of Mass Flow Rate of Steam

Estimating the total steam production is important to determine the energy loss carried away by the steam. Direct measuring of steam flow velocity using ultra sonic flow meter is impossible. Due to unknown reason, the velocity of steam flow fluctuates within a wide range. Hence, the alternative way to estimate the mass flow rate of steam is using water mass balance of the boiler. From visual inspection of the boiler, no leakage is observed. Therefore, feed water is the only input mass and blow down and steam are the output masses. The mass balance of steam is given by:

$$m_s = m_{fw} - m_{bd} \dots\dots\dots (5.17)$$

Where

m_{fw} – Mass flow rate of feed water = 35,591.4 kg/day (0.507 kg/sec)

m_{bd} – Mass flow rate of blow down = 290.358 kg/day (0.0849 kg/sec)

m_s – Mass flow rate of steam

5.3.7.5. Analysis of mass flow rate of vent steam

Vent steam is one of the major sources of thermal energy losses. The mass flow rate can be calculated by directly multiplying of vent steam flow velocity, area of the pipe, and the density of vent steam.

$$m_{vs} = V_{vs} A_{vs} \rho_{vs} \dots\dots\dots (5.18)$$

Where

$$\rho_{vs} - \text{Density of vent steam} = \frac{1}{V_v} = \frac{1}{0.001065 \frac{m^3}{kg}} = 938.9 \frac{kg}{m^3}$$

V_{vs} – Velocity of vent steam = 0.106 m/sec

A_{vs} – Area of vent steam flow pipe = 0.000358 m²

5.3.8. Determination of the input energy in the boiler

Thermal energy audit analysis of boiler was conducted to know thermal and combustion efficiency of boiler. The analysis was done based on the energy inputs and outputs of the boiler. All inputs and outputs of the boiler are shown in Figure 5.1.

These sources of input energy of the boiler are discussed in the following headings.

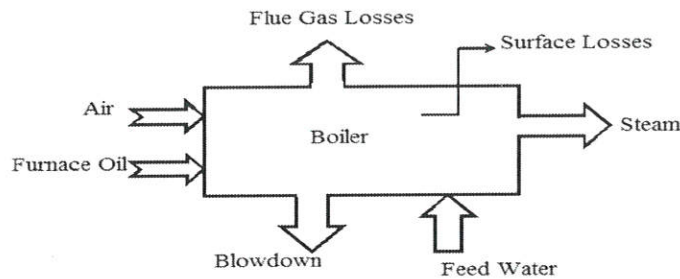


Figure 5-1 Boiler input and output

5.3.8.1. Furnace oil energy

The furnace oil contains chemical energy and heat energy by virtue of its chemical components and pre-heating of the fuel at inlet to the boiler respectively.

5.3.8.1.1. Chemical energy of furnace oil

The chemical energy of the furnace oil is quantified using its heating value. To calculate the energy efficiency of the boiler on GCV, the chemical energy of the furnace oil must be found. The chemical energy of the furnace oil is obtained by multiplying GCV of the fuel with the mass flow rate of the fuel. From table 6.1 and the value of GCV and mass flow rate of the furnace oil; hence, the chemical energy of the fuel can be obtained by:-

$$Q_f = m_f(\text{GCV}) \dots \dots \dots (5.19)$$

Where

Q_f – Chemical energy of the fuel

m_f –Mass flow rate of the fuel = 0.04148 kg/sec

GCV – Gross calorific value of the fuel = 10,500 kcal/kg (43,961 kJ/kg)

5.3.8.1.2. Energy due to fuel pre-heating

The energy due to fuel pre-heating is the enthalpy of furnace oil by virtue of its temperature elevation relative to the atmospheric temperature. The enthalpy of furnace oil due to its pre-heating from the ambient temperature to pre-heating temperature can be obtained using the following thermodynamic path.

$$[\text{Furnaceoil}]_{27^\circ\text{C}} \rightarrow [\text{Furnaceoil}]_{115^\circ\text{C}}$$

The pre-heating temperature can be determined using the following equation

$$Q_{\text{pre-heating}} = m_f C_f (T_f - T_a) \dots \dots \dots (5.20)$$

Where

$Q_{\text{pre-heating}}$ – Energy content due to fuel pre-heating



C_f – Specific heat of fuel = 0.879 kJ/kg °k [21]

T_f – Temperature of fuel pre-heating = 115 °C

T_a – Ambient temperature = 27 °C

m_f = Mass flow rate of fuel = 0.04148 kg/sec

5.3.8.2. Energy of combustion air

The inlet air temperature is at ambient temperature. Since the enthalpy of the flue gas is calculated relative to the temperature of the entering air, the relative enthalpy of combustion air is zero.

$$Q_{com} = 0 \dots\dots\dots (5.21)$$

5.3.8.3. Energy of feed water

The energy of feed water is the enthalpy of water by virtue of its temperature elevation relative to the atmospheric temperature. The enthalpy of feed water due to its pre-heating from the ambient temperature to pre-heating temperature can be obtained using the following thermodynamic path.

$$[\text{Feedwater}]_{27^\circ\text{C}} \rightarrow [\text{Feedwater}]_{80^\circ\text{C}}$$

Energy of feed water can be determined using the following formula

$$Q_{fw} = m_{fw}C_w(T_{fw} - T_a) \dots\dots\dots (5.22)$$

Where

Q_{fw} – Feed water energy

m_{fw} – Mass flow rate of feed water = 0.507 kg/sec

C_w – Specific heat of water = 4.18 kJ/kg°k [21]

T_{fw} – Feed water temperature = 80 °C

T_a – Ambient temperature = 27 °C

5.3.9. Determination of the output energy of the boiler [11]

The energy losses or output of the boiler integrate with the burning of fuel in the combustion chamber and boiler losses are mentioned here and analysis one by one.

- Dry flue gases loss analysis
- Heat loss due to evaporation of water formed due to H₂ in fuel
- Heat loss due to moisture content of air
- Heat loss due to radiation and convection from the boiler surface
- Heat loss due to moisture content of the fuel
- Boiler blow down water from the boiler drum

➤ Useful heat loss to steam

5.3.9.1. Dry flue gases loss analysis

The energy loss due to dry flue gas leaving the boiler can be obtained using the mass flow rate of dry flue gas and enthalpy change of dry flue gas at flue gas temperature relative to the ambient temperature of flue gas. The analysis is performed using the equation here below.

$$\dot{Q}_{\text{flue}} = \dot{m}_{\text{flue}} \times C_p(T_{\text{flue}} - T_a) \dots\dots\dots (5.23)$$

Where

$\dot{Q}_{\text{dry gas}}$ = Heat loss due to dry flue gas

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

C_p – Specific heat capacity of dry flue gas = 1.35 kJ/kg⁰k [32]

T_{flue} - Flue gas temperature = 228 °C

T_a - Ambient temperature = 27 °C

5.3.9.2. Heat loss due to evaporation of water formed due to H₂ in fuel

Throughout combustion process of the furnace oil the hydrogen contained in it reacts with oxygen and water will be formed. The water formed takes away some of the energy liberated during the combustion process. This energy loss due to presence of hydrogen in the furnace oil can be calculated as:

$$Q_{H_2} = (M)_{H_2O} \times (\dot{m}_f)[h_{fg@27^\circ C} + C_p(T_{\text{flue}} - T_a) \dots\dots\dots (5.24)$$

Where

$\dot{m}_f$ – Mass flow rate of fuel = 0.04148 kg/sec

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

$h_{fg@27^\circ C}$ – Enthalpy of water = 2430.352 kJ/kg

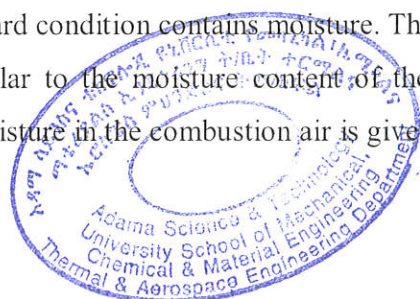
C_p – Specific heat capacity = 1.88 kJ/kg⁰k [32]

T_{flue} – Flue gas temperature = 228 °C

T_a – Ambient temperature = 27 °C

5.3.9.3. Heat loss due to moisture content of air

The air used for combustion under standard condition contains moisture. The energy loss due to moisture content of the air is similar to the moisture content of the furnace oil described above. The energy loss due to moisture in the combustion air is given by:



$$Q_{\text{moisture}} = \text{AAS} \times \gamma_A \times (\dot{m}_f)[C_p(T_{\text{flue}} - T_a)] \dots\dots\dots (5.25)$$

Where

AAS – Actual air supplied 29.32 kg of air / kg of fuel

$\gamma_A = 0.01507$ kg of H₂O/kg of dry air

5.3.9.4. Heat loss due to radiation and convection from the boiler surface

As wind crosses over the surface of the boiler, energy will be lost from the boiler surface to the wind by convection. In addition to this, due to difference in temperature between the ambient air and the boiler surface there is also radiation energy loss. The energy loss due to convection and radiation in watt per unit area of the boiler surface exposed to the ambient temperature condition is given by:- [11]

$$Q_{RV} = \{0.548[(\frac{T_s}{55.55})^4 - (\frac{T_a}{55.55})^4] + 1.957(T_s - T_a)^{1.25} \sqrt{\frac{196.85V + 68.9}{68.9}}\} \frac{W}{m^2} \times S_{FCB} \dots\dots\dots (5.26)$$

Where

T_s – Surface temperature for cylindrical, front and back is 316 °K, 379 °K and 381 °K respectively.

T_a – Local ambient temperature for cylindrical, front and back is 304 °K, 306 °K and 309 °K respectively.

S_{FCB} – Boiler surface area of front, cylindrical and back side is 7.07 m², 37.69 m² and 7.07 m² respectively.

V – Wind speed = 0 m/sec for all sides. (The boiler is working in closed room)

5.3.9.5. Heat loss due to moisture content of the fuel

Through combustion process of the furnace oil, due to the presence of moisture in it water will be formed. The water formed takes away some of the energy liberated during the combustion process. This energy loss due to moisture in the furnace oil is given by:

$$Q_M = (M) \times (\dot{m}_f)[h_{fg@27^\circ C} + C_p(T_{\text{flue}} - T_a)] \dots\dots\dots (5.27)$$

Where

$Q_{M_{\text{fuel}}}$ = Heat loss due to moisture in fuel

$\dot{m}_f$ – Mass flow rate of fuel = 0.04148 kg/sec

C_p – Specific heat capacity = 1.88 kJ/kg⁰K [32]

T_{flue} – Flue gas temperature = 228 °C

T_a – Ambient temperature = 27 °C

$h_{fg@27^\circ C}$ – Enthalpy of water = 2430.352 kJ/kg

M – Moisture in fuel = 0.5%

5.3.9.6. Boiler blow down water from the boiler drum (blow down loss) [5]

The factory uses tap water as feed water to the boiler. As it is already discussed, the water contains impurities. To protect unnecessary accumulation of impurity, the factory practice intermittent blow down from the boiler. This is an energy loss. The energy loss due to boiler blow down is given by

$$Q_{bd} = \dot{m}_{bd} \times h_{f@115^\circ\text{C}} \dots\dots\dots (5.28)$$

Where

$\dot{m}_{bd}$ – Mass flow rate of blow down = 0.0849 kg/sec

$h_{f@115^\circ\text{C}}$ – Enthalpy of blow down = 463.2 kJ/kg

5.3.9.7. Useful heat loss to steam

One of the major energy output is the heat carried away by the steam. The amount of heat energy carried away by the steam is obtained by multiplying the amount of steam produced per second by the enthalpy. The enthalpy is given in steam table, and the flow rate, temperature and pressure can be observed from gauges mounted on the boiler as stated in Table 5.2. The output energy can be obtained using equation.

$$Q_{\text{steam}} = \dot{m}_{\text{steam}} \times h_{gs} \dots\dots\dots (5.29)$$

h_{gs} – Enthalpy of super heated steam at a temperature of 187.4 °C and pressure of 13 bar = 2772.85 kJ/kg

$\dot{m}_{\text{steam}}$ – Mass flow rate of steam = 0.5521 kg/sec

Q_{steam} – Heat carried away by the steam

5.3.9.8 Analysis of energy losses of the produced steam

5.3.9.8.1 Analysis of energy loss due to vent steam

The factory is venting the extra amount of steam produced. Vent steam is one of the major thermal energy losses of the produced steam. The thermal energy loss in the vent steam is given by-

$$Q_v = \dot{m}_v \times h_{fv@128^\circ\text{C}} \dots\dots\dots (5.30)$$

Where

$h_{fv@128^\circ\text{C}}$ – Enthalpy of vent steam = 529.9 kJ/kg

$\dot{m}_v$ – Mass flow rate of vent steam = 0.0356 kg/sec



5.3.9.9 Boiler efficiency

Boiler efficiency, which does account for radiation and convection loss, is a true indication of overall boiler efficiency. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses. As prescribed by the ASME Power Test Code, PTC 4.1, the boiler efficiency can be determined by two method; the input-output Method [12, 21].

5.3.9.9.1 Boiler efficiency based on input-output method

In this method, the energy gains of the working fluid (feed water and steam) are compared with the energy content of the boiler fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. The boiler working pressure and temperature is 13 bar and 187°C respectively and the temperature of feed water is 80°C.

This efficiency can be evaluated using the formula.

$$\eta = \frac{\dot{m}_s(h_{gs}-h_{fs})}{\dot{m}_f(GCV)} \dots\dots\dots (5.31)$$

Where

$\dot{m}_s$ – Quantity of steam generated per second = 0.5521 kg/sec

$\dot{m}_f$ – Quantity of fuel used per second = 0.04148 kg/sec

h_{gs} – Enthalpy of super heated steam = 2772.85 kJ/kg

h_{fs} – Enthalpy of feed water = 384.91 kJ/kg

GCV – Gross calorific value of fuel = 10,500 kcal/kg (43,961 kJ/kg)

5.3.9.9.2 Energy efficiency of the boiler based on heat loss method

The heat balance efficiency measurement method is based on accounting of all the heat losses of the boiler. The actual measurement method consists of subtracting from 100 percent the total losses. The resulting value is the boiler fuel to steam efficiency. This method further classified as thermal efficiency of the boiler and combustion efficiency of the boiler.

5.3.9.9.3 Thermal efficiency of the boiler

The thermal efficiency of the boiler based on heat loss method on GCV is given by

$$\eta_{th} = [1 - \frac{\text{outputenergylosses}}{\text{inputenergy}}] \times 100\% \dots\dots\dots (5.32)$$

5.3.9.9.4 Combustion efficiency of the boiler

The combustion efficiency of the furnace based on heat loss method on GCV is given by

$$\eta_{com} = [1 - \frac{\text{outputenergylosses}}{\text{inputenergy}}] \times 100\% \dots\dots\dots (5.33)$$

5.3.10 Assessment of boiler shell losses

As it is clearly indicated in the heat balance sheet and conclusion remarks of the boiler, the summation of energy input to boiler and the summation of energy output are not equal. As the result, the net heat liberated in the furnace and the actual heat gain by the feed water are different. This may be due to energy loss at the boiler shell. Thus, the shell energy loss of the boiler on GCV is given equation 5.34.

$$Q_{sellGCV} = \eta_{th}(\text{sum of all output energy} - \text{sum of input energy}) \dots\dots\dots (5.34)$$

The overall efficiency of the boiler is given by summation of shell energy loss to the output losses.

$$\eta_{Overall} = [1 - \frac{\text{outputlosses} + Q_{sell}}{\text{energyinput}}] \times 100\% \dots\dots\dots (5.35)$$

5.4. Result and discussion

5.4.1. Analysis of boiler energy performance

To perform the thermal energy audit of the boiler using first law of thermodynamic, that is the combustion and boiler efficiency, thermal energies that are entering and leaving the boiler must be calculated. The energy efficiency analysis was done based on the energy input and output of the boiler. To accomplish the energy analysis of the boiler the following

Using equation 5.1, 5.2 and 5.3 it can be determine the boiler dimensions. There are three surfaces cylindrical, front and back which are exposed to the ambient. Calculated areas for sides of the boiler are

$$A_{front} = A_{back} = 7.07 \text{ m}^2$$

$$A_{cylindrical} = 37.69 \text{ m}^2$$

Energy and mass balance

To calculate the energy and mass balance of the boiler the following terms should be calculated first.

5.4.1.1. Heating value of furnace oil

The net calorific value of furnace oil can be estimated by subtracting the total enthalpy of vaporization of water due to its hydrogen and moisture content. Using equation 5.4 and 5.5 the net calorific value of furnace oil calculated



$$\text{NCV} = 41,336.47 \text{ kJ/kg}$$

5.4.1.2. Furnace oil combustion

To calculate the energy loss during furnace oil combustion, analysis of mass and energy during combustion, combustion air and combustion elements are important.

Elements of combustion air

To perform molar analysis of the combustion air elements, the absolute humidity and mass fraction of air elements relative to oxygen should be determined first.

Using equation 5.6, 5.7 and 5.8 to calculate absolute humidity factor.

$$(\gamma_A) = 0.622 \times \left(\frac{2.397 \text{ kPa}}{98.928 \text{ kPa}} \right) = 0.015071 \frac{\text{kg of } H_2O}{\text{kg of dry air}}$$

Mass fraction of air elements relative to oxygen

To accomplish the actual chemical balance during burning of furnace oil with atmospheric air it is quite necessary to normalize mass fraction of the major air composition to handle the mass balance of the elements relative to oxygen and this procedure is discussed in Table 5.6.

5.4.1.3. Air fuel ratio of furnace oil burning

The theoretical and actual air fuel ratio of furnace oil burning on mass basis is important to determine the flow rate of flue gases.

5.4.1.3.1. Theoretical air-fuel ratio (TAR)

To determine the theoretical air-fuel ratio of burning furnace oil, a standard chemical reaction must be established which oxidizes 1kg of furnace oil completely into carbon dioxide and water with inert nitrogen in the product stream. The standard chemical reaction of furnace oil is the burning of 1kg of furnace oil using dry air [11]. The percentage of fuel elements is presented in Table 5.5.

Theoretical air fuel ratio is given by equation 5.8. Using this equation the TAR was calculated.

$$\text{TAR} = 13.964 \text{ Kg/kg of furnace oil}$$

5.4.1.3.2. Actual air-fuel ratio of furnace oil (AA)

The actual mass of air used during burning of one kg of fuel in boiler furnace can be found from equation 5.10. The ARFR is

$$\text{AAR} = 29.89 \text{ Kg of air/kg of oil}$$

Therefore, from this result it can be seen that the theoretical air-fuel ratio (i.e. 13.964 kg/kg of furnace oil) and the actual air-fuel ratio (i.e. 29.89 kg/kg of furnace oil) have

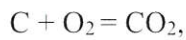
significant differences. The actual air-fuel ratio deviates with a magnitude of 15.36 from the recommended value (i.e. 15 %) and shows too much excess inlet air was supplied to the boiler of the factory.

5.4.1.3.3. Mass flow rate of dry flue gas

To find out the mass flow rate of the dry flue gases the composition of the gas products of the actual chemical reaction in the boiler should be determined first.

From equation 5.11 and 5.12 the mass flow rate of flue gas and composition of fuel with 110 % EA were calculated

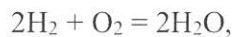
Elements of fuel: -



$$12+32=44$$

12kg of C requires 32 kg of O_2 to form 44kg of CO_2 therefore 1kg of C requires 32/12 kg of O_2 . (2.67 kg of O_2)

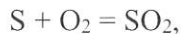
$$0.84 * C + 0.84 * 2.67 * O_2 = \underline{3.083 CO_2}$$



$$4+32=36$$

4 kg of H_2 requires 32 kg of O_2 to form 36kg of H_2O , therefore 1kg of H_2 requires 32/4 kg of O_2 (8kg of O_2)

$$0.12 * H_2 + 0.12 * 8 * O_2 = \underline{1.08 H_2O}$$



$$32+32=64$$

32 kg of S requires 32 kg of O_2 to form 64 kg of SO_2 , therefore 1 kg of S requires 32/32 kg of O_2 (1 kg of O_2)

$$0.015S + 0.015 * 1 * O_2 = \underline{0.03 SO_2}$$

$$EA = AAS - TAR$$

$$= 29.32 \text{ kg of air} - 13.964 \text{ kg of air} = 15.36 \text{ kg of air}$$

$$\text{Excess } O_2 = 15.36 \text{ kg} * 0.23 \text{ (by mass)} = 3.53 \text{ kg}$$

$$\text{Excess } N_2 = 15.36 \text{ kg} * 0.77 \text{ (by mass)} = 11.83 \text{ kg}$$

The final composition of flue gas with 110 % EA for 1kg of fuel is the summation of compositions

$$CO_2 = 3.083 \text{ kg/kg of fuel}$$

$$H_2O = 1.08 \text{ kg/kg of fuel}$$

$$SO_2 = 0.03 \text{ kg/kg of fuel}$$

$$O_2 = 3.53 \text{ kg/kg of fuel}$$



$$N_2 = 11.83 \text{ kg} + 10.34 \text{ kg} = 22.17 \text{ kg/kg of fuel}$$

$$= 29.89 \text{ kg/kg of fuel}$$

The total mass of flue gas (m) = 29.89 kg of flue/kg of fuel

Multiplying 29.89 kg of flue gas/kg of fuel with the mass flow rate of furnace oil gives the mass flow rate of flue gases

$$m_{flue \text{ gas}} = 1.239 \frac{kg_{flue}}{sec}$$

Furnace combustion temperature

$$T_{furnace} = 605.9 \text{ }^{\circ}\text{C}$$

Specific heat of dry flue gases

For furnace oil the specific heat of dry flue gas was calculated by equation 5.13.

$$C_{p_{fg}} = 1.353 \frac{Kcal}{kg^{\circ}C}$$

5.4.2. Determination of mass flow rate of the boiler

In order to calculate the boiler input and output energy, the mass flow rate of: furnace oil, blow down, feed water and steam should be determined first. The results of mass flow rates were presented in Table 5.7.

Table 5-8 Mass flow rate of the boiler

No	Mass flow rate	kg/sec	kg/day	Equation
1	Furnace oil	0.04148	2,911.90	5.14
2	Feed water	0.507	35,591.40	5.15
3	Blow down	0.0849	290.358	5.16
4	Steam	0.5521	35,301.04	5.17
5	Vent steam	0.0356	75.61	5.18

5.4.3. Determination of the input energy in the boiler

To determine the input energy of the boiler we need to identify the input parameters. Furnace oil due to its pre-heating, combustion air and feed water are the input energy of the boiler and energy of feed water and energy of combustion air are considered as input energy of the boiler.

Using equations 5.19, 5.20, 5.21, and 5.22 respectively to determine the boiler input energy. The results were presented in Table 5.8.

Table 5-9 Input energy of the boiler

No	Input energy	kW
1	Chemical energy of fuel (Q_f)	1,823.50
2	Energy of fuel due to pre-heating ($Q_{\text{pre-heating}}$)	3.21
3	Energy of combustion air (Q_{com})	0
4	Energy of feed water (Q_{fw})	112.32
5	Sum of input energy	1,939.03

5.4.4. Determination of the output energy of the boiler

All losses due to different reasons obtained by using different equations. The losses were presented in Table 5.10 with equation number.

Table 5-10 Output energy from the boiler

No	Output energy	kW	Equation number
1	Due to dry flue gas	336.2	5.23
2	Due to H_2 in fuel	125.8	5.24
3	Due to moisture in fuel	0.582	5.27
4	Due to moisture in air	6.93	5.25
	Sum of output energy (1-4)	469.51	
5	Due to surface loss	20.2	5.26
6	Due to blow down loss	39.33	5.28
	Output energy (1-6)	529.04	
7	Due to heat carried away by steam	1,491.95	5.29
	Total output energy	2,020.99	

5.4.5. Mass balance for the combustion process

The mass balance for the combustion process is consisting of actual air supplied and furnace oil as an input mass and excess oxygen, nitrogen, carbon dioxide and sulfur dioxide as an output mass. Summary of mass balance for the combustion process is presented in Table 5.11 and 5.12.



Table 5-11 Input masses in to boiler

Items	Mass (kg)
Actual air supplied	29.32
Fuel	1
Total input mass	30.32

Table 5-12 Output masses into boiler

Items	Mass (kg)
O ₂	3.53
CO ₂	3.083
H ₂ O	1.08
SO ₂	0.03
N ₂	22.17
Total mass output	29.893

5.4.5.1. Final comment on the heat and mass balance of the boiler

The difference between input outputs mass is (0.427), which is an acceptable. This difference might be the results of measuring error. For the heat balance of the boiler for 100 % input energy to the boiler 73.3 % is lost. This indicates that the summation of input energy and output energy are not matching for the boiler. These differences are may be due to shell energy loss of the boiler, which can be considered as energy saving opportunities.

5.5. Boiler efficiency [3]

Boiler efficiency can be determine based on

Input-output method using equation 5.31

$$\eta = \frac{0.5521(2772.85 - 384.91)}{0.04148(43961)} \\ = 72.3 \%$$

Energy efficiency of the boiler based on heat loss method

Thermal efficiency of the boiler

The thermal efficiency of the boiler based on heat loss method on GCV is given by equation 5.32.

$$\eta_{th} = \left[1 - \frac{529.04}{1939.03}\right] \times 100\% \\ = 72.7 \%$$

Combustion efficiency of the boiler

The combustion efficiency of the furnace based on heat loss method on GCV is given by equation 5.33.

$$\eta_{com} = \left[1 - \frac{469.51}{1939.03}\right] \times 100\% \\ = 75.8 \%$$

Boiler shell loss

The shell energy loss of the boiler on GCV is given by

$$Q_{sellGCV} = \eta_{th}(\text{sum of all output energy} - \text{sum of input energy}) \dots\dots\dots (5.34)$$

Therefore, the assumptions of boiler shell losses can be calculated.

$$Q_{sell} = 0.733(2020.99 - 1939.03) \\ = 60.07 \text{ kW}$$

The overall efficiency of the boiler is given by equation 5.35.

$$\eta_{Overall} = \left[1 - \frac{529.04 + 60.07}{1939.03}\right] \times 100\% \\ = 69.6 \%$$

5.6. Energy sankey diagram of the boiler

The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment after carrying out energy balance calculation. This diagram represents visually various output and losses so that energy managers can focus on finding improvements in a prioritized manner [28]. The energy Sankey diagram of the boiler is drawn using the heat balance sheet on Table 5.9 and 5.10, and is revealed in figure 5.2.



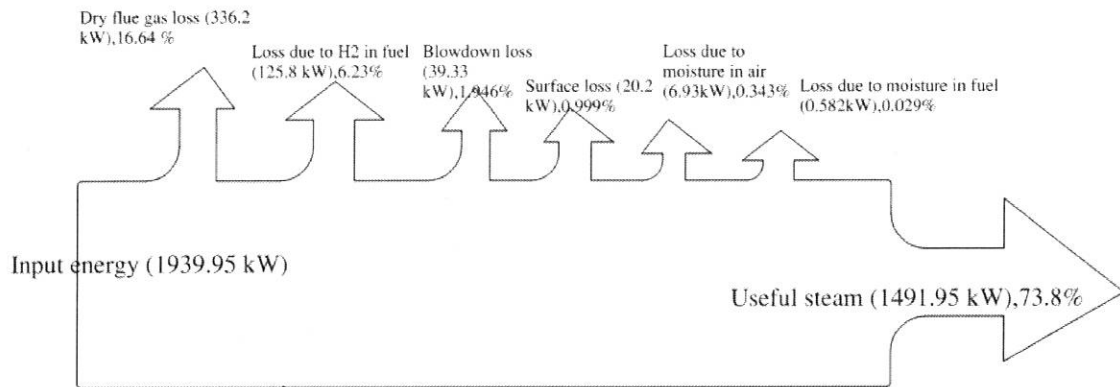


Figure 5-2 Sankey diagram of the boiler

5.7. General comment of the energy performance of the boiler

The energy efficiency of the boiler of the factory is found to be 72.7 %. This efficiency is less than the expected performance of a new furnace oil fired boiler, which is equal to 85 % [21]. The main causes that contribute to the significant drop in efficiency of the boiler is the energy loss due to

- Loss of sensible heat of the dry flue gas (16.64 % efficiency loss of boiler)
- Loss due to the present of H₂ in fuel (loss due to latent heat) (6.23 % efficiency loss of boiler)
- Loss due to the moisture content of combustion air (0.343 % efficiency loss of boiler)
- Loss due to the moisture content of fuel (0.029 % efficiency loss of boiler)
- Loss of heat by radiation and convection from boiler surface (0.999 % efficiency loss of boiler)
- Boiler blow down loss (1.946 % efficiency loss of boiler)
- Boiler shell loss (2.553 % efficiency loss of boiler)
- Loss due to vent steam (0.939 %)

The energy loss due to furnace oil hydrogen content and moisture in combustion air and fuel are unavoidable losses. However, energy loss due to dry flue gases and boiler shell energy losses can be reduced. Hence, minimizing these energy losses are considered as energy saving opportunities that could significantly improve the energy efficiency of the boiler.

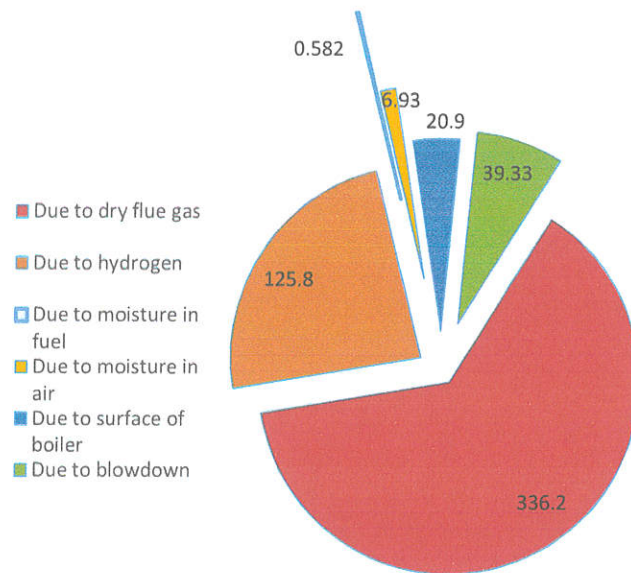
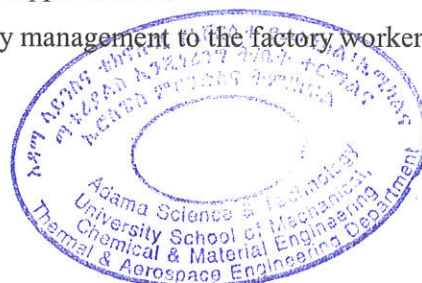


Figure 5-3 Boiler losses in Pie chart

5.8. Identification of energy saving opportunities of the analysis

Energy conservation opportunities for boiler are identified from inspection, interview, and detail energy audit conducted.

- From detailed energy audit conducted, the following energy saving opportunities were identified:
 - Boiler surface is not insulated
 - Most of the steam distribution systems are not insulated
 - The flue gas temperature is greater than the recommended range due to malfunctioning of an economizer.
 - Boiler feed water treatment plant is failed. As a result, the boiler operates with improperly treated feed water, which leads it to energy loss.
 - The combustion efficiency of the boiler is low due to excess air admitted (110 %) (Beyond the recommended value of 15 %)
 - The combustion efficiency of the boiler is low due to large percent of excess air is admitted to the combustion chamber.
 - The total steam demand of the factory is 4.3 TPH. But the boiler was designed to produce 6 TPH. The extra amount of the produced steam is removed by means of venting and throttling, therefore the boiler is oversized.
- Housekeeping energy conservation opportunities:
 - Lack of awareness on energy management to the factory workers



- The soot is not removed with a regular time interval
- Excessive blow down is done by operators
- The Boiler is working with adjusted pressure range of 9 to 14 bars. It is automatically adjusted to stand and stop at 9 and 14 bars respectively. Throughout this condition, the boiler needs high fuel consumption to restart (boilers are not allowed to work in such conditions)

5.9. Technical evaluation of energy saving opportunities

According to detail energy audit of the boiler, saving energy in the factory boiler is a question of improving combustion efficiency and improving feed water treatment. In agreement with this fact, the result of energy audit conducted in this chapter revealed that there is a considerable energy savings potential in the boiler of the factory through improving the boiler efficiency, which reduces the energy losses, listed above. Therefore, the technical feasibility analysis of insulating boiler surface, maintaining and repairing an economizer, repairing water treatment plant, reducing the amount of excess air and replacing the boiler with proper size are discussed here under.

5.10 Technical evaluation of improving efficiency of furnace

The efficiency of a furnace oil fired boiler is 85 % on GCV [11]. From the energy analysis conducted above the efficiency of the boiler is 72.7 %. This implies that the factory furnace waste about 26.7 % of the energy input on gross calorific value. This waste indicate that attention to the details of the energy wastages causes must be investigated and measures must be taken to improve the energy efficiency of the furnace to save energy.

The main cause of energy losses in the furnace are energy loss due to moisture content of combustion air, moisture and hydrogen content of furnace oil and excess energy loss due to dry flue gas. From the above mentioned sources of energy losses in the furnace, the only controllable loss is energy loss due to dry flue gas. This energy loss can be minimized or controlled to an optimum level through controlling the excess air admitted in to the furnace. For furnace oil fired furnace the recommended percent excess air admitted to the furnace is 15% with the volume percent of CO₂ is also 15 % [11]. However, the average excess air supplied to the furnace of the factory boiler is 110 % with the volume percent of CO₂ being 3.083 %. The technical analysis of controlling excess air is performed for the recommended percentage i.e.15 % as follows. When the excess air percentage used for combustion is changed to 15 %, a type of energy loss in the furnace that is affected is energy loss due to dry flue gas. To find this energy loss at 15 % of excess air and the corrected efficiency,

- Theoretical air fuel ratio,
- Actual air supplied,
- Mass flow rate of the flue gas and
- Furnace temperature must be determined as is done in the audit phase.

5.10.1. Calculation of the air-fuel ratio

5.10.1.1. Theoretical air-fuel ratio

The theoretical amounts of air require to burn the furnace oil at the given percent of the elements of the furnace oil can be determined by using equation 5.8.

$$TAR = 13.964 \text{ kg of air/kg of fuel}$$

5.10.1.2. Actual air - fuel ratio of furnace oil (AAR) at 15 % excess air

Using equation 5.9 the actual mass of air used during burning of one kg of fuel in boiler furnace is

$$\begin{aligned} AAR &= \left[1 + \frac{15}{100} \right] \times 13.964 \text{ kg of } \frac{\text{air}}{\text{kg}} \text{ of fuel} \\ &= 16.07 \text{ kg of } \frac{\text{air}}{\text{kg}} \text{ of fuel} \end{aligned}$$

5.10.1.3. Excess air quantity

The quantity of excess air can be determined by subtracting theoretical air required from the actual amount of air supplied.

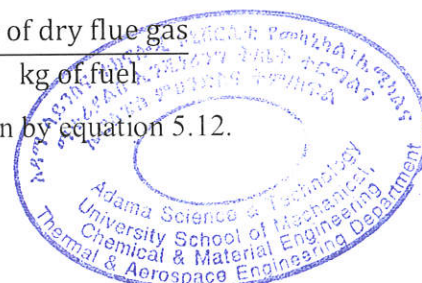
$$\begin{aligned} EA_Q &= AAS - TAR \dots\dots\dots (5.35) \\ &= 16.07 - 13.964 \\ &= 2.12 \text{ kg of air} \end{aligned}$$

5.10.2. Mass flow rate of dry flue gas with 15 % of excess air

To calculate the energy losses due to dry flue gases (stack loss), the mass flow rate of the flue gases must be calculated. To find the mass flow rate of the dry flue gases the composition of the gaseous products of the actual chemical reaction in the boiler must be determined first. The elements of dry flue gases are CO₂, SO₂, N₂ and O₂. The mass of each elements of dry flue gas is given by equation 5.11. Using this equation the mass of dry flue gas is

$$m_{\text{dry flue gas}} = 16.027 \frac{\text{kg of dry flue gas}}{\text{kg of fuel}}$$

Therefore, mass flow rate of dry flue gas is given by equation 5.12.



$$\begin{aligned}
 m_{\text{dry flue gas}} &= 16.0268 \frac{\text{kg of flue gas}}{\text{kg of fuel}} \times 0.04148 \frac{\text{kg}}{\text{sec}} \\
 &= 0.665 \frac{\text{kg of flue gas}}{\text{sec}}
 \end{aligned}$$

5.10.3. Combustion temperature of furnace and C_p at 15 % EA

For 0.5 % of moisture content of furnace oil at 15 % of excess air the temperature of furnace is 722.6 °C [7]

The mean specific heat given by equation 5.13.

$$C_p = 1.371 \frac{\text{kJ}}{\text{kg}^\circ\text{C}}$$

5.10.4. Energy loss due to dry flue gas

The energy loss due to dry flue gas at 15 % excess air can be calculated using the following equation assuming linear increase in flue gas temperature because of the increase in furnace temperature, the energy loss due to dry flue gas is given by equation 5.23.

$$\begin{aligned}
 Q_{\text{dry flue gas}} &= 0.665 \frac{\text{kg of flue}}{\text{sec}} \times 1.371 \frac{\text{kJ}}{\text{kg}^\circ\text{C}} (267.41 - 27) \\
 &= 219.19 \text{ kW}
 \end{aligned}$$

Table 5-13 Input output at 15 %

No	Input (kW)		Output (kW)	
1	Fuel due to heat	1823.5	Dry flue gas loss	219.19
2	Feed water	112.32	Due to moisture in air	6.93
3	Sensible heat	3.21	Due to moisture in fuel	0.582
4	Combustion air	0	Due to hydrogen in fuel	125.8
	Total (1-4)	1939.03	Total (1-4)	352.5

5.10.5. Calculation of the Combustion efficiency at 15 % excess air

Using the equation 5.33 the combustion efficiency of the furnace at 15 % of excess air is

$$\begin{aligned}
 \eta_{\text{comb}} &= \left[1 - \frac{352.5}{1939.03} \right] \times 100\% \\
 &= 81.8\%
 \end{aligned}$$

The above technical analysis indicates that the furnace efficiency can be improved by correcting the excess air percentage admitted into the furnace. Thus, controlling the excess air is technically feasible for energy saving opportunities.

5.10.6. Insulating boiler surface

Boiler surface temperature is high relative to the ambient temperature. As a result, boiler lost 20.2 kW heat to the environment. To avoid this lose, insulating boiler surface is taken as energy conservation opportunities.

Technically it is not a difficult task for the factory to apply this as energy management opportunity. However, it should be checked for the cost effectiveness of it.

5.10.6.1. Saving analysis

By assuming 80 % of the surface losses will be recovered by the suitable insulation, the saved energy will be 16.16 kW from 20.2 kW of surface loss. This saves 10,116 liters fuel (1 kW = 626 liter) of fuel which is equivalent with 164,385 Birr per year. Another basic saving while we conduct insulation is environmental saving. Emissions of greenhouse gases will reduce.

5.10.6.2. Implementation cost

The thickness of insulation is assumed 40 mm (adequate insulation thickness). It is taken from scenario results of 3Eplus: a computer program developed by the North American Insulation Manufacturers Association, NAIMA that provides the user with a simplified and systematic method for determining adequate insulation thickness. The following are data inputs for the insulation cost calculation.

- The bare, un-insulated wall needs a material cost of 82.5 Birr per square meter
- Overhead cost is fixed at 35.75 Birr per square meter
- Base labor cost is 60.5 Birr per square meter and
- Additional labor cost is 3.025 Birr per square meter

The total cost per square meter is the sum of the above mentioned costs and becomes 181.775 Birr. The total surface of the boiler is 51.83 m². Therefore, the total cost for boiler insulation will be 9,421.39 Birr. From this, we can decide, as it is an economically feasible measure.

5.10.6.3. Payback period

The simple payback period can be estimated as follows:

$$\text{simple payback period} = \frac{\text{implementation cost}}{\text{saved cost}} \dots\dots\dots (5.36)$$

$$\begin{aligned} &= \frac{9,421.39 \text{ birr}}{164,385 \frac{\text{birr}}{\text{year}}} \\ &= 0.057 \text{ year } (\cong 1 \text{ month}) \end{aligned}$$



5.11. Installing economizer

The factory boiler is without economizer. Economizer is recommended for boilers installed without it if the following points are fulfilled. [17], [11]

- Operating hours of boiler greater than 2500 hr/year,
- Stack gas flow rate greater than 6852 kg/year,
- Average stack gas temperature greater than 232 °C ,
- High excess air, and
- Ambient temperature for is in the rage of 11 to 28 °C.

In addition to these, there are other basic factors should be included while we recommend economizer. These include:

- Time required to install (at least a year),
- Human resource to install and then operate it,
- Space available in the factory, and
- Initial implementation cost.

In AMASSASCO the following boundaries are observed:

- High excess air (i.e. 110 %)
- Stack gas flow rate is greater than 6852 kg/hrs. (i.e. 8694 kg/hrs.)
- Ambient temperature is in the rage of 11 to 28 °C (i.e. 27 °C)
- Average stack gas temperature is lower than 232 °C (i.e. 228 °C)
- Operating hours of boiler is greater than 2500 hrs/year (i.e. 6734.25 hrs/year).

Though the above most criteria are fulfilled, installing economizer is not technically feasible. Because there is no space available and human resource in the factory to install the economizer. Initial investment cost, availability of the machine (no factory can manufacture it inside our country) and time required to install it are other determinant factors. Based on these it is technically infeasible. As a result it is not necessary to discuss the economic analysis.

5.12. Technical evaluation of maintaining and repairing an economizer.

The flue gas living from boiler is at a temperature of 228 °C. The higher stack temperature implies the greater percent of sensible energy loss during the combustion process this lowers the energy efficiency of the combustion process. Therefore, the stack temperature should be as low as possible. However, it should not be so low that water vapor in the exhaust condenses on the stack walls. Typically, for the furnace oil, the flue gas exit temperature from a boiler is usually maintained at approximately 200 °C, so that the sulfur oxides in the

flue gas do not condense and cause corrosion of heat transfer surfaces [21]. Thus reducing the stack temperature to the recommended value i.e. 200 °C for preheating the feed water offers increase in overall thermal efficiency of the boiler. Installing an economizer can reduce the flue gas exit temperature. The technical feasibility study of maintaining and repairing an economizer needs skilled labor. At current physical condition of the factory, there is no skilled technician to maintain and repair an economizer. Thus installing new economizer is very expensive so, the factory needs to skilled person.

5.13. Technical evaluation of repairing water treatment plant

Repairing the water treatment unit is not technically difficult task in every aspect (time required, initial cost, human resource, space availability) and can be done by the factory workers. Repairing this unit will increase the efficiency of boiler and its lifetime. If it is technically feasible, the economic feasibility analysis will check.

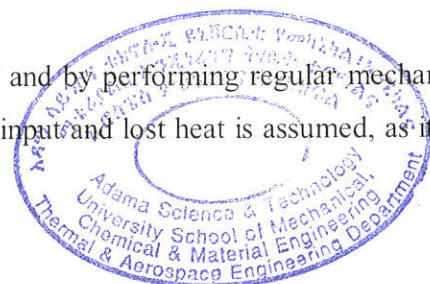
The factory boiler is highly affected by scale deposits on its waterside. Scale deposits results in efficiency losses and may result in boiler tube failures and incapability to produce proper amount of steam. Scale deposits act as insulators and slow heat transfer. Large amounts of scale deposits throughout the boiler could reduce the heat transfer to the level enough to reduce the boiler efficiency significantly. This scale deposits in the boiler is resulted from hardness contamination and corrosion products of feed water system. Hardness contamination and corrosion products of the feed water arise due to the malfunctioning of water treatment plant in the factory. The energy losses due to malfunction of factory water treatment plant is shell energy losses.

The boiler shell energy loss is 303.68 kW. This loss can be minimized by controlling the TDS level of feed water (repairing water treatment plant) and mechanical cleaning of the waterside of the boiler.

The technical feasibility study of repairing water treatment plant entails intensive research on the behaviors of feed water property, pressure developing unit and pressure sand filters of the water treatment plant. At the current physical condition of the factory repairing or replacing pressure developing unit and pressure sand filters of the water treatment plant are possible. Therefore repairing water treatment plant is technically feasible. If it is technically feasible, the economic feasibility analysis will checked as follow.

5.13.1. Saving analysis

Energy can be saved by pre-treating feed water and by performing regular mechanical cleaning on the boiler side. The deviation between input and lost heat is assumed, as it is a



result of built up shell in the boiler (by considering vent steam loss insignificant). If the feed water is treated properly this loss will be avoid. As a result, the saved energy can be estimated as follows.

$$\begin{aligned}\text{Saved energy} &= \eta_{th}((\text{all losses} + \text{usefull energy}) - \text{input energt}) \dots\dots\dots (5.37) \\ &= 0.733(2020.99 - 1939.03)\text{kW} \\ &= 60.08 \text{ kW}\end{aligned}$$

The total amount of energy saved by repairing the water treatment plant is 60.08 kW. This heat is equivalent to saving of 37,610.08 liters per year (1 kW = 626 liter) and 611,163.8 Birr per year (1liter = 16.25 birr).

5.13.2. Implementation cost

The estimated cost for repairing the factory water treatment plant ranges from 20,000 Birr to 30,000 Birr and the cost of typical rotating equipment used for cleaning of fire tube boilers ranges from 52,500 to 87,500 Birr depending on size and feature. Adding 47 % [8] additional cost on the direct maximum cost of purchasing the repairing equipment's for transportation and other related costs, the cost of having functional water treatment plant will be

$$= 30,000 \times 1.47 = 44,100 \text{ Birr}$$

The cost of having the cleaning equipment's will be

$$= 87,500 \times 1.47 = 128,625 \text{ Birr}$$

Thus the total cost will be the sum of the two and became

$$\begin{aligned}&= (44,100 + 128,625) \text{ Birr} \\ &= 172,725 \text{ Birr}\end{aligned}$$

5.13.3. Payback period

The simple payback period for water treatment unit can be estimated by using equation 5.36.

$$\begin{aligned}\text{simple payback period} &= \frac{172,725\text{birr}}{611,163.8 \frac{\text{birr}}{\text{year}}} \\ &= 0.283 \text{ year } (\cong 3.4 \text{ month})\end{aligned}$$

5.14. Technical evaluation of replacing the existing boiler

The existing factory boiler is design to produced 6 TPH of steam at 15 bar & 187 °C. From energy analysis the amount of total steam consumed by factory processes are 4.3TPH of steam at 1bar & 160 °C. Due to over sizing, live steam is partly exhausted to the ambient; throttling is to bring down 15 bar pressure to 1 bar and less. This energy loss can be

minimized or controlled by replacing the boiler with proper sized boiler. At the current physical condition of the factory, replacing the existing boiler with proper sized boiler is possible. Therefore, replacing the boiler is technically feasible.

5.15. Economic evaluation of replacing the boiler

5.15.1. Saving analysis

The energy saved in replacing the existing boiler is given by

$$\text{Energy saved} = \dot{m}_{\text{saved}} \times h_{g@187^\circ\text{C}\&13\text{bar}} \times \eta_{\text{com}@15\%} \dots\dots\dots (5.38)$$

$$\text{But } \dot{m}_{\text{saved}} = (\text{produced steam} - \text{steam demand})$$

Taking 10% margin on steam demand

$$= 4.3 \times 1.1 = 4.73 \text{ TPH}$$

$$= (6 \text{ TPH} - 4.73 \text{ TPH})$$

$$= 1.27 \text{ TPH} \left(0.3528 \frac{\text{kg}}{\text{sec}} \right)$$

Therefore, the energy saved can be

$$\text{Energy saved} = \dot{m}_{\text{saved}} \times h_{g@187^\circ\text{C}\&14\text{bar}} \times \eta_{\text{com}@15\%}$$

$$= 0.3528 \frac{\text{kg}}{\text{sec}} \times 2778.95 \frac{\text{kJ}}{\text{kg}} \times 0.818$$

$$= 801.9 \text{ kW}$$

The equivalent liter of fuel and money saved is 508,249.4 litre and 8,259,052.8 Birr per year respectively.

5.15.2. Implementation cost

The cost of a typical boiler (6 TPH @ 150 °C & 1 bar) is ranges from \$250,000-\$300,000 (5,843,750 – 7,012,500 Birr) depending on manufacturers, whereas the salvage value of the existing boiler is approximately 6,428,125 Birr.

5.15.3. Payback period:

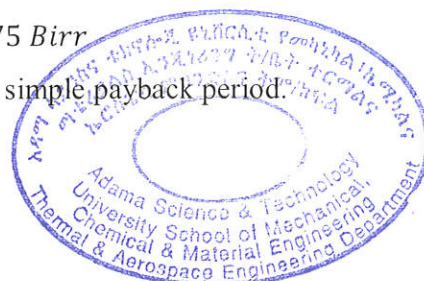
The simple payback period can be found by dividing the cost saved with the cost of boiler. Adding 47 % [32] additional cost on the direct maximum cost of purchasing the boiler for transportation and other related costs the cost of having new boiler will be

$$1.47 \times 6,428,125 = 9,449,343.75 \text{ Birr}$$

Subtract the salvage value from the new boiler cost

Implementation cost will be = 3,021,218.75 Birr

Using equation 5.36 it can be estimated the simple payback period.



Simple payback period = 0.367 year *or* = 4.5 month

5.16. Economic evaluation of controlling the excess air by reducing motor capacity

5.16.1. Saving analysis

The percent energy saved in correcting the excess air to 15 % is given by

$$\text{energy saved} = m_{\text{fuel}} \times \text{GCV}[\eta_{\text{com@15\%}} - \eta_{\text{com actual}}] \dots \dots \dots (5.39)$$

$$= 0.04148 \frac{\text{kg}}{\text{sec}} \times 43,961 \frac{\text{kJ}}{\text{kg}} [0.818 - 0.764]$$

$$= 98.47 \text{ kW}$$

The equivalent amount of fuel and money saved is 61,642.22 liter and 1,001,686.07 Birr per year respectively.

5.16.2. Implementation cost analysis

The implementation cost of controlling the excess air can be attained by calculating the capacity of the fan motor in providing 15 % excess air to the furnace. To calculate the fan motor capacity the optimum operating parameter of steam generators must be known in advance. From the experience obtained from the audit stay and log sheet the fan motor capacity can be calculated taking the following optimum operating parameters for the factory steam generator:

Steam generation 6 TPH at 15 bar and 187 °C super-heated temperature. Feed water inlet temperature at 80 °C and exhaust gas temperature at 228 °C. To find the capacity of the fan for the above optimum parameters the following calculations are essential: the heat load, fuel consumption, and volume flow rate of flue gas and the static pressure head of the fan.

5.16.2.1. Calculation of heat load of the boiler

The total heat load of the boiler can be calculated by summing up heat absorbed to get super-heated steam and blow down heat loss.

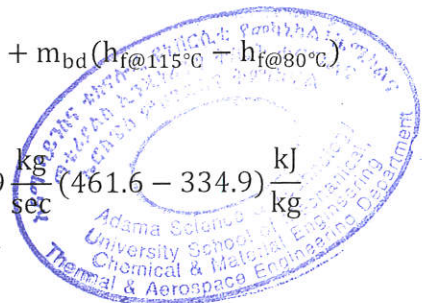
Mathematically

$$\text{Total Heat Load} = m_{\text{steam}}(h_{g@187^\circ\text{C}\&14\text{bar}} - h_{f@8\text{bar}}) + m_{\text{bd}}(h_{f@115^\circ\text{C}} - h_{f@80^\circ\text{C}}) \dots \dots \dots (5.40)$$

$$= 0.4221 \frac{\text{kg}}{\text{sec}} (2778.95 - 763.11) \frac{\text{kJ}}{\text{kg}} + 0.0849 \frac{\text{kg}}{\text{sec}} (461.6 - 334.9) \frac{\text{kJ}}{\text{kg}}$$

$$= (850.89 + 10.76) \text{ kW}$$

$$= 861.65 \text{ kW}$$



5.16.2.2. Fuel consumption of the boiler

Fuel consumption of the boiler is given by dividing the heat load to gross calorific value and the combustion efficiency at 15 % excess air.

$$\begin{aligned}\text{Fuel consumption} &= \frac{\text{Heat Load}}{\text{GCV} \times \eta_{\text{com@15\%}}} \dots\dots\dots (5.41) \\ &= \frac{861.65 \frac{\text{kJ}}{\text{sec}}}{43,961 \frac{\text{kJ}}{\text{kg}} \times 0.818} \\ &= 0.0239 \frac{\text{kg}}{\text{sec}}\end{aligned}$$

5.16.2.3. Volumetric flow rate of flue gases

The volumetric flow rate of the wet flue gases can be found by multiplying the total flow rate of flue gas by the specific volume of the wet gas and it is given by

$$V = m_{\text{flue gas}} \times v_{\text{flue gas}} \dots\dots\dots (5.42)$$

Calculation of the total mass flow rate of flue gas

The total mass flow rate of the exhaust gases produced is given by the following equation

$$m_{\text{flue gas}} = m_{\text{fuel}} \times w_{\text{flue gas}} \dots\dots\dots (5.43)$$

However, unit weight of gas per kg of fuel is given by

$$\begin{aligned}w_{\text{flue gas}} &= \text{AAS} + (1 - \text{ash}) \dots\dots\dots (5.44) \\ &= 16.07 + (1 - 0) \\ &= 17.07 \text{ kg of air/kg of fuel}\end{aligned}$$

Therefore, the total mass flow rate of exhaust gases produced is

$$\begin{aligned}m_{\text{flue gas}} &= m_{\text{fuel}} \times w_{\text{flue gas}} \\ &= 0.0239 \frac{\text{kg}}{\text{sec}} \times 17.07 \frac{\text{kg of air}}{\text{kg of fuel}} \\ &= 0.408 \frac{\text{kg}}{\text{sec}}\end{aligned}$$

Calculation of the specific volume of wet gas

The formula used for calculating the specific volume of the wet flue gas is given by equation

$$\begin{aligned}v_{\text{flue gas}} &= v_{\text{air}} \frac{T_{\text{flue}}}{T_{\text{air}}} \dots\dots\dots (5.45) \\ &= \frac{271 + 273.15}{27 + 273.15} = v_{\text{air}}(1.813)\end{aligned}$$

However, the specific volume of the combustion air is calculated by

$$v_{\text{air}} = \frac{RT}{P} \dots\dots\dots (5.46)$$

$$= \frac{0.287 \times 297}{83.96} = 1.02 \frac{\text{m}^3}{\text{kg}}$$

$$\begin{aligned} \text{So, } v_{\text{flue gas}} &= 1.02 \times 1.813 \\ &= 1.85 \frac{\text{m}^3}{\text{kg}} \end{aligned}$$

Therefore the volumetric gas flow rate at flue gas temperature is

$$\begin{aligned} V &= m_{\text{flue gas}} \times v_{\text{flue gas}} \\ &= (0.408 \times 1.85) \frac{\text{m}^3}{\text{kg}} \\ &= 0.751 \frac{\text{m}^3}{\text{kg}} \end{aligned}$$

Taking 20 % margin on flow, the actual volumetric gas flow will be

$$\begin{aligned} V_{\text{flue gas}} &= (1 + 20\%) \times 0.751 \frac{\text{m}^3}{\text{kg}} \\ &= 0.901 \frac{\text{m}^3}{\text{kg}} \end{aligned}$$

5.16.2.4. Calculation of fan static head

The following relations give the fan static head h

$$h = \text{Draft loss (in boiler + Duct + Dust collector)} \dots\dots\dots (5.47)$$

$$= 5 + 10 + 60 \text{ mm WC: (from factory recommended draft value)}$$

$$= 75 \text{ mm WC}$$

Taking 20 % margin on head, the fan head will be

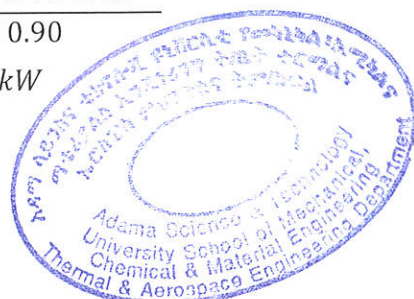
$$h = 75 \times 1.2 = 90 \text{ mmWC}$$

5.16.2.5. Motor power capacity of the fan

Assuming fan efficiency as 75 % and motor efficiency as 90 % the motor capacity for the fan is given by the equation

$$P = \frac{\gamma_{\text{H}_2\text{O}} V_{\text{flue gas}} h}{\eta_{\text{fan}} \eta_{\text{motor}}} \dots\dots\dots (5.48)$$

$$\begin{aligned} &= \frac{9810 \times 0.901 \times 90 \times 10^{-3}}{0.75 \times 0.90} \\ &= 1.18 \text{ kW} \end{aligned}$$



5.16.2.6. Concluding remark on the actual power rating of the fan

The power rating of the combustion fan motor of the factory boiler is 7.4 kW. From motor data measurement of Table 7.1, the motor load factor is 41.6 % of the rated power. This implies the actual energy supplied to the combustion fan motor is 5 kW. Thus, the power supplied to the boiler motor is excess which must be reduced to improve the energy efficiency of the boiler.

5.16.2.7. Implementation cost of the combustion fan motor

The implementation cost of the combustion fan is given by the following

Implementation cost of fan = cost of motor + installation + operating cost

The yearly cost of operation is given by

$$\begin{aligned} \text{Yearly Operation Cost} &= P_{\text{fan}} \times 24\text{hr} \times 300\text{day} \times \text{electric rate} \dots\dots\dots (5.56) \\ &= 1.18\text{kW} \times 7200\text{hr} \times 0.55 \text{ Birr/kWh} \\ &= 4,248 \frac{\text{Birr}}{\text{year}} \end{aligned}$$

The installation cost of the motor is taken to be 47 % of the combustion fan motor cost.

So,

Implementation cost of the combustion fan

$$\begin{aligned} &= 1.47 \times \text{motor cost} + \text{operating cost} \\ &= 1.47 \times 12,000 + 4,248 \\ &= 21,888 \text{ Birr} \end{aligned}$$

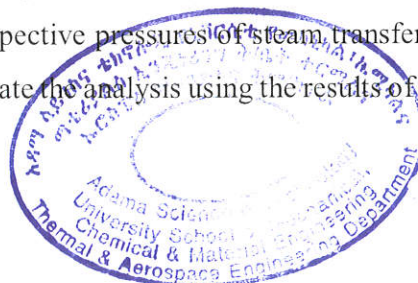
5.16.3. Payback period

The simple payback period is determined by dividing the investment cost by the annual returns on the investment. Using equation 5.36.

$$\text{payback period} = \frac{21,888 \text{ Birr}}{491,636.93 \frac{\text{Birr}}{\text{year}}} = 0.046 \text{ year } (\cong 1\text{month})$$

5.17. Audit of steam distribution systems

Most of the factory steam distribution systems are bare even they are exposed for rain in the rainy season. From these the main are the pipes (they are two in number) which distribute steam to the process and the analysis included in this thesis work is for these only. Though there is no measuring gauge mounted to these steam distribution systems, which show the mass flow rate, and respective pressures of steam transferred and vent out from each systems, it is possible to estimate the analysis using the results of 3Eplus computer



program. Insulation is not technically difficult task though it is not adapted in our country. If it is technically feasible, the economic feasibility analysis will be done as follows. The pipes have an average of 114.6 °C temperatures throughout their length (30 m for each).

5.17.1. Saving analysis

The difference between heat loss from bare pipe and insulated pipe is the energy savings associated with insulation. The yearly energy savings by installing insulation for steam supply pipelines of both aluminum sulphate and sulfuric acid can be determined from 3Eplus computer program. For 40mm insulation, the total saved money will be 28,846.28 birr per year per pipe.

$$\begin{aligned}\text{Saved money} &= (2 \times 28,846.28) \frac{\text{birr}}{\text{year}} \\ &= 57,692.56 \frac{\text{birr}}{\text{year}}\end{aligned}$$

5.17.2. Implementation cost

From 3Eplus computer program, the cost for 40 mm insulation thickness for 30 m length pipe is estimated as 15,546.66 Birr. For the two pipes, the implementation cost will be 31,093.32 Birr.

5.17.3. Payback period

Simple payback period can be estimated by equation 5.36.

$$\begin{aligned}\text{SPBP} &= \frac{31,093.32 \text{ Birr}}{57,692.56 \frac{\text{Birr}}{\text{year}}} \\ &= 0.54 \text{ year} \cong 6.5 \text{ month}\end{aligned}$$

5.18. Summary of technical and economical feasible

The following are technical as well as economical feasible energy saving opportunities that play crucial role in improving the boiler efficiency is

- Insulating the boiler surface
- Repairing water treatment plant,
- Replacing the existing boiler with proper sized boiler
- Keeping the percentage of the excess air within the recommended range, and

The summary of the energy saving recommendations and the priority for post audit analysis are summarized in Table 5.10.



Table 5-14 Summary of energy recommendations

	Energy saving opportunities	Annual saving (Birr)	Investment cost (Birr)	SPBP (month)
1	Insulating boiler surface	164,385	9,318.45	1
2	Repairing water treatment plant	1,360,063.25	172,725	1
3	Replacing existing boiler	8,259,052.80	3,021,218.75	4.5
4	Controlling excess air by reducing fan motor capacity	491,636.93	21,888	1
5	Steam distribution system	57,692.56	31,093.32	6.5

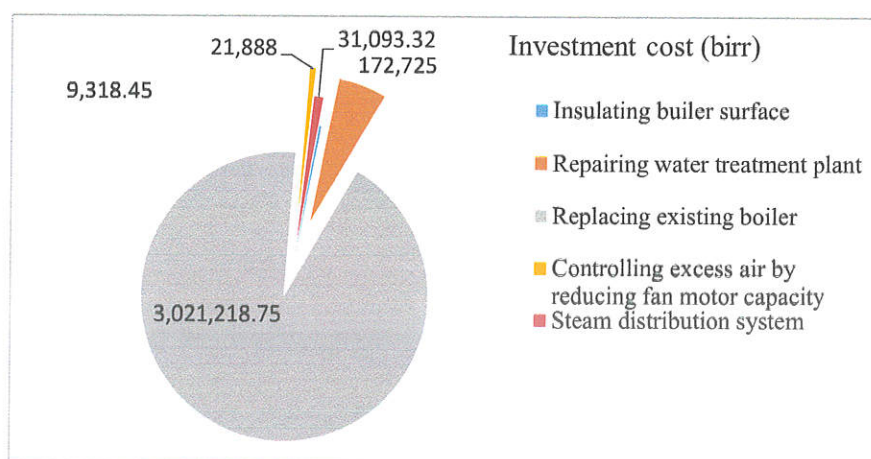


Figure 5-4 Investment cost (birr)

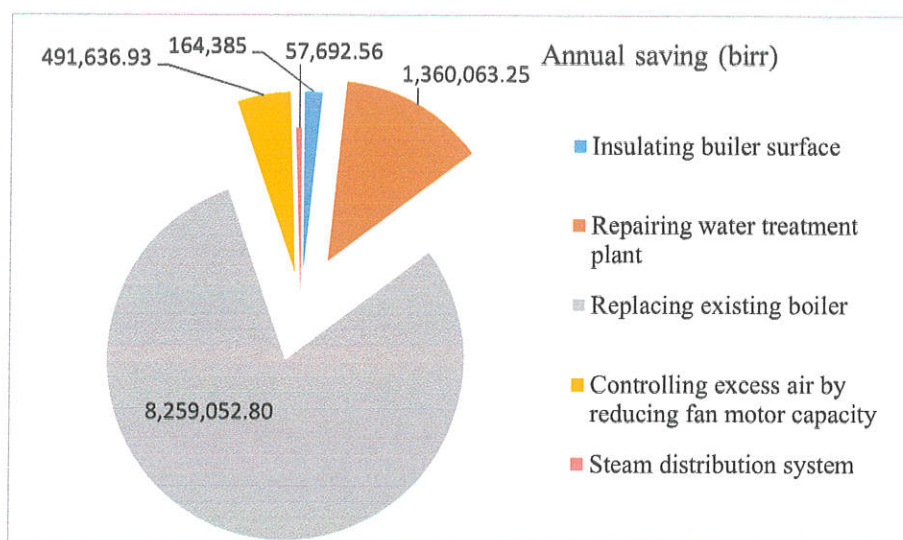


Figure 5-5 Annual saving (birr)



CHAPTER SIX

6. DETAILED ENERGY ASSESSMENT OF MOTORS AND PUMPS

6.1. Introduction

In the factory, there are different motors with their driven devices. Almost all motors made by Poland company which is installed overall the factory, some motors from the Italian company and from German company are also there. The factory uses more than 20 motors that drive pumps. Some of these motors are very old (about 22 years old) and the remaining is 10 to 12 year old.

Pump systems consist of pumps, driver, pipe installation and controls (such as throttles) and are a part of the overall motor system. Below some of the energy efficiency opportunities for the pumping system are presented.

Improving the efficiency of electric motors and the equipment's they drive can save energy, reduce operating costs, and improve the productivity of the factory. In order to evaluate the energy performance of motors with its driven machines, different data were collected at motors and pumps by taking measurements using portable measuring instruments, referring from nameplate of the machines, visual inspection, and interviewing the workers. Therefore, the detail energy audit of these major driven machines with its motors can be performed through assessment of their energy performance.

The factory installed three phase AC induction motors with rated power capacities within the range of 0.55 to 18 kW as seen from the nameplate which drive different pumps for different purpose.

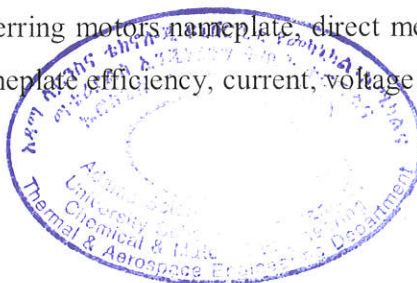
The power factors, efficiencies, service years, and operating hours of the factory motors are: 0.80 to 0.88, 0.81 to 0.88, 10 to 22 years, and 365.0 hours per year to 8424 hours per year, respectively.

6.2. Data collection

6.2.1. Collection of data for motors

In the factory more than 20 motor. All of them installed when the factory was constructed so, it tells us almost all motors were very old and there was a lot of vibration and noise heard during operation of the pump indicating that the motor was not smoothly operating.

The data collecting was done by referring motors nameplate, direct measurement using portable instruments. These include nameplate efficiency, current, voltage and power factor



and measured line current, terminals voltage and input power. The list of the factory motors with their functions.

M_A - Motors at treatment plant to drive water to the water tank

M_B - Motors at pre-treatment to cooling tower and treatment plant

M_C - Motors at the cooling tower to distribute to the plant

M_D - Motors at the boiler to feed furnace oil to the boiler

M_E - Motors at the boiler to feed treated water to the boiler

M_F - Motors at Awash River

M_G - Motors to feed aluminum sulphate to filter press

M_H - Motors to feed reactors to reaction tank

M_I - Motors to feed backwash to the reaction tank

M_J - Motors to feed sulfuric acid to reaction tank

M_K - Motors to feed aluminum sulphate to evaporation tank

M_L - Motors at the cooling tower to return back from the process

M_M - Motors for air compressor

Table 6-1 Motors value from nameplate

Motors	Nameplate values (rated)					
	Voltage(v)	Current(I)	$\cos\phi(PF)$	RPM	Standard Efficiency(η)	Phase
M_A	380	7.7	0.83	1460	82.5	3
M_B	380	2.8	0.83	1580	80	3
M_C	380	12	0.87	1473	86.4	3
M_D	280	8	0.87	1400	85.6	3
M_E	380	7	0.87	3280	86	3
M_F	380	33	0.85	2850	85	3
M_G	380	3.5	0.84	1475	82	3
M_H	380	5	0.84	1470	80	3
M_I	400	14	0.87	2930	86	3
M_J	380	5	0.84	1440	80	3
M_K	380	6.5	0.88	3280	85.7	3
M_L	380	5	0.84	1440	80	3



Table 6-2 Measured motors data

Motors	Measured motor values			
	Power(kW)	Voltage	Current I	$\cos\phi(PF)$
M _A	2.5	380.7	4.8	0.77
M _B	0.96	380.8	1.74	0.71
M _C	2.32	379.7	7.47	0.78
M _D	1.62	379.3	4.98	0.73
M _E	2.1	380.7	5.2	0.85
M _F	9.6	381	17.5	0.83
M _G	0.72	379.6	1.35	0.81
M _H	1.4	380.6	2.59	0.82
M _I	3.2	389.3	11.3	0.86
M _J	1.38	379.3	2.67	0.79
M _K	2	379.1	4.5	0.83
M _L	1.01	381	2	0.77

It can be seen that from Table 6.1 and 6.2 that the actual power factors and the nameplate power factors are different. This shows that the power utilization performance of motors is lowered due to their power factor failures.

6.2.2. Data collection for pumps

The data collection methods are same as the motors data collection methods. These include measured fluid flow velocity, pump head and pipe diameters. The measurements are taken using portable measuring instruments, borrowed from the factory instrumentation department, direct reading from gauge and daily reports of the operators. Annual operating hours and fluid density are other areas referred to take the correct data. The collected data's are presented in the following tables. Evaluating a pump system to increase system efficiency and reduce energy costs, can be evaluated with respect to energy costs and utility rate structures, hydraulic system efficiency, mechanical efficiency, and electrical efficiency.

Pumps are designated by:

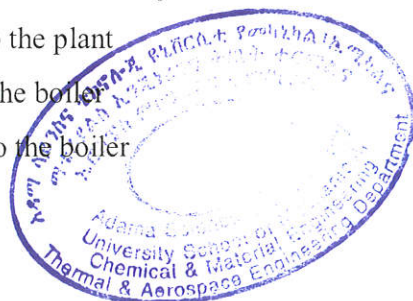
P_A = Pump at treatment plant to drive water to the water tank

P_B = Pump at pre-treatment to cooling tower and treatment plant

P_C = Pump at the cooling tower to distribute to the plant

P_D = Pump at the boiler to feed furnace oil to the boiler

P_E = Pump at the boiler to feed treated water to the boiler



P_F = Pump at Awash River

P_G = Pump to feed aluminum sulphate to filter press

P_H = Pump to feed reactors to reaction tank (Sulfuric acid)

P_I = Pump to feed backwash to the reaction tank (Aluminium sulphate)

P_J = Pump to feed sulfuric acid to reaction tank

P_K = Pump to feed aluminum sulphate to evaporation tank

P_L = Pump at the cooling tower to return back from the process

P_M = Pump for air compressor

Table 6-3 Rated values of pumps

Pumps	Rated values of pumps		
	Densities kg/m ³	Flow rate m ³ /hr	Head H (m)
P _A	1000	5	40
P _B	1000	9.6	40
P _C	1000	60	30
P _D	991	3	45
P _E	1000	5	45
P _F	1000	6.5	40
P _G	881	40	30
P _H	1830	5	40
P _I	881	3	45
P _J	1830	5	40
P _K	881	3	45
P _L	1000	20	30

Table 6-4 Measured values of pumps

Pumps	Measured values of pumps			
	Diameter, D (m)	Speed V (m/sec)	Head H (m)	Operating hrs.
P _A	0.0956	0.47	4.27	7336
P _B	0.0508	0.156	3.38	7436
P _C	0.242	0.473	3.4	7536
P _D	0.044	0.0498	9.1	5184
P _E	0.0956	0.49	4.38	6336
P _F	0.0508	0.124	4.25	8336
P _G	0.0953	5.46	2.1	8426
P _H	0.0508	1.31	9.1	7652



P _I	0.0254	0.135	2.91	8232
P _J	0.0508	0.193	2.35	6465
P _K	0.0331	4.98	2.91	8225
P _L	0.0635	0.0757	10.8	7223

Even though there are many pumps with their driving motors in the factory, only those having motor load factor less than 40% are included in this investigation. This is by considering the fact that pumps driven by motors operating with optimum part load have no significant effect on the overall energy performance of the factory.

6.3. Data analysis

6.3.1. Input power of the motor

The input power of the motor can be determined by the following equation

$$R_{\text{rated power}} = \frac{I \times V \times \cos \phi \times \sqrt{3}}{1000} \dots\dots\dots (6.1)$$

$R_{\text{rated power}}$ = Input power to the motor

V = Nameplate voltage

I = Nameplate current

6.3.2. Load factor

The load factor can be obtained by dividing the actual (measured) electric power to the rated power of the motor. The expression used for calculating the load factor of the motors is given by the following equation.

$$L_f = \frac{P_{\text{measured}}}{P_{\text{nameplate power}}} \dots\dots\dots (6.2)$$

Where:

L_f = Load Factor

$P_{\text{nameplate}}$ = Power from nameplate reading

P_{measured} = Measured input power

6.3.3. Power factor

The formula that used to calculate the actual power factor is

$$\cos \phi = \frac{P_{\text{measured}}}{V_{\text{meas}} \times I_{\text{meas}} \times \sqrt{3}} \dots\dots\dots (6.3)$$

$\cos \phi$ = Power factor

V_{meas} = Measured voltage



I_{meas} = Measured current

$P_{measured}$ = Measured input power (electrical power)

6.3.4. Mechanical power

The nameplate motor efficiency is used to calculate the mechanical power of the motors.
Thus, the mechanical power of the motor is given by equation:-

$$P_{mech} = \eta_{nameplate} \times P_{measured} \dots\dots\dots (6.4)$$

Where:

$\eta_{nameplate\ reading}$ = Nameplate Efficiency

$P_{measured}$ = Measured power

$P_{mechanical}$ = Mechanical power

6.3.5. Volume flow rate of fluid

The volume flow rate of the fluid is given by the following equation:-

$$\dot{Q} = V_{fluid} \times A_{pipe} \dots\dots\dots (6.5)$$

Where:

$\dot{Q}$ = Volume flow rate of the fluid

A_{pipe} = Pipe area of pumps, i.e $A_{pipe} = \frac{\pi D^2}{4}$

V_{fluid} = flow velocity of fluid

6.3.6. Power gained by the fluid

The output power gained by the pumps due to fluid passing through them is given by equation 6.6.

$$P_{output} = \frac{\rho \times g \times \Delta H \times \dot{Q}}{1000} \dots\dots\dots (6.6)$$

Where:

P_{output} = Power gained by the fluid

ρ = Density of the fluid

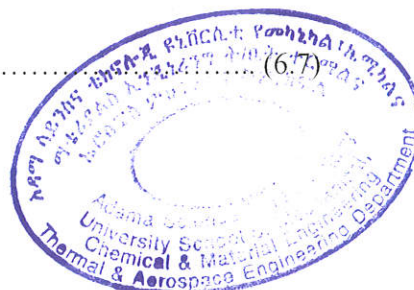
$\dot{Q}$ = Volume flow rate of the fluid

H = Pump head

6.3.7. Pump efficiency

Pump efficiency is given by equation 6.7.

$$\eta_{pump} = \frac{P_{out}}{P_{in}} \dots\dots\dots (6.7)$$



Where:

η_{pum} = Efficiency of Pumps

P_{out} = Power gained by the fluid

P_{in} = Input power to the pump

6.3.8. Overall efficiency

The overall efficiency of pumps with their motors can be calculated by dividing output power (power gained by the fluid) to input power of the motor (electrical energy).

$$\eta_{overall} = \frac{P_{out}}{P_{measured}} \dots\dots\dots (6.8)$$

Where:

$\eta_{overall}$ = Overall efficiency of pumps

$P_{measured}$ = Measured electrical power

P_{out} = Power gained by the fluid

6.4. Results and discussion pumps and motors

6.4.1. Input power of motors

Using equation 6.1, we can determine the input power of each motor that is presented in Table 6.3.

Table 6-5 Input powers to the motors

Motors	M_A	M_B	M_C	M_D	M_E	M_F	M_G	M_H	M_I	M_J	M_K	M_L
$P_{rp}(\text{kW})$	4.2	1.53	6.9	3.4	4	18.5	1.9	2.8	8.4	2.8	3.8	2.8

6.4.2. Load factors of the motors

Using equation 6.2, we can calculate the load factor of each motor from Table 6.1 and 6.2.

Table 6-6 Load factor of motors

Motors	M_A	M_B	M_C	M_D	M_E	M_F	M_G	M_H	M_I	M_J	M_K	M_L
L_f	0.66	0.62	0.34	0.48	0.53	0.52	0.38	0.50	0.38	0.49	0.53	0.36



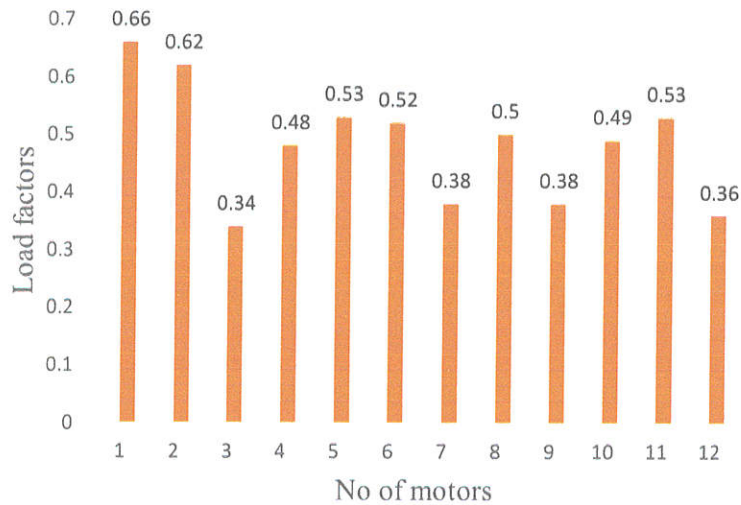


Figure 6-1 Motors load factors

The average optimum load factor of motors is 40 % [29]. But, we can see from Table 6.6 as the calculated load factor values for motors M_C , M_G , M_I and M_L have load factors below the recommended value. This shows motors are working with under load condition which results energy wastage. The cost due to these includes initial cost of motors with high un-recommended nameplate power motor. Though the load factors of the remaining motors show as they are working with part load, they are in the recommended range.

6.4.3. Power factor of the motors

Using equation 6.3, we can calculate the power factor of the motors as follows

Table 6-7 Calculated power factor

Motors	M_A	M_B	M_C	M_D	M_E	M_F	M_G	M_H	M_I	M_J	M_K	M_L
P_f	0.88	0.83	0.47	0.49	0.61	0.83	0.81	0.81	0.42	0.78	0.67	0.76

6.4.4. Mechanical power of the motors

Using equation 6.4, it is possible to calculate mechanical power for each motor.

Table 6-8 Mechanical power of motors

Motors	M_A	M_B	M_C	M_D	M_E	M_F	M_G	M_H	M_I	M_J	M_K	M_L
$\eta_{namepl}(\%)$	0.82	0.80	0.86	0.85	0.86	0.85	0.82	0.80	0.86	0.80	0.857	0.80
$P_{meas}(\text{kW})$	2.79	0.96	2.32	1.62	2.1	9.6	0.72	1.4	3.2	1.38	2	1.01
$P_{mecha}(\text{kW})$	2.3	0.77	1.99	1.38	1.8	8.2	0.59	1.12	2.75	1.1	1.71	0.82



6.4.5. Volume flow rate of the pump

Using equation 6.5 and Table 6.3 it is possible to determine the volume flow rate of the fluid, once we have the pipe diameter of the pipe it is possible to determine the cross sectional area of the pipe. The tabulated data will be presented here below in Table 6.9.

Table 6-9 Volume flow rate of the fluid

Pumps	P _A	P _B	P _C	P _D	P _E	P _F	P _G	P _H	P _I	P _J	P _K	P _L
V _{fl} (m/s)	0.47	0.156	0.47	0.049	0.49	0.124	5.46	1.32	0.135	0.193	4.98	0.076
A _{pipe} (m ²)	0.0072	0.002	0.046	0.0015	0.0072	0.002	0.0071	0.002	0.0005	0.002	0.0009	0.0032
Q (m ³ /s)	0.0034	0.0003	0.022	0.0008	0.0035	0.0003	0.039	0.0027	0.00007	0.0004	0.0043	0.00024
Q (m ³ /hr)	12.24	1.08	79.2	2.88	12.6	1.08	140.4	9.72	0.252	1.44	15.48	0.864

6.4.6. Power gained by the fluid

Using equation 6.6, the results were presented in Table 6.10

Table 6-10 Power gained by fluids

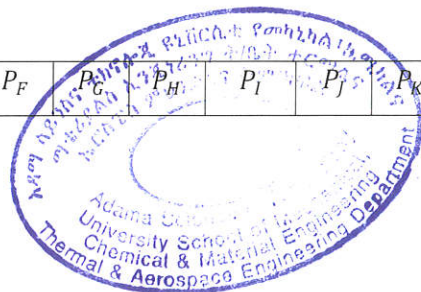
Pumps	Head H(m)	Density (kg/m ³)	Flow rate $\dot{Q}$ (m ³ /s)	Power (P_{out}) kW
P _A	4.27	1000	0.0034	0.15
P _B	3.38	1000	0.0003	0.001
P _C	3.4	1000	0.022	2.4
P _D	9.1	991	0.0008	0.072
P _E	4.38	1000	0.0035	0.153
P _F	4.25	1000	0.0003	0.013
P _G	2.1	881	0.039	2.9
P _H	9.10	1830	0.0027	0.45
P _I	2.91	881	0.00007	0.002
P _J	2.35	1830	0.0004	0.02
P _K	2.91	881	0.0043	0.11
P _L	10.8	1000	0.00024	0.03

6.4.7. Pump efficiency

Using equation 6.7, calculated efficiency of pumps was tabulated in Table 6.11.

Table 6-11 Efficiencies of pump

Pumps	P _A	P _B	P _C	P _D	P _E	P _F	P _G	P _H	P _I	P _J	P _K	P _L
-------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------



P_{out} (kW)	0.15	0.001	0.75	0.07	0.15	0.13	0.7	0.45	0.002	0.02	0.11	0.03
P_{in} (kW)	2.3	0.77	1.99	1.38	1.8	8.2	1.59	1.12	2.75	1.1	1.7	0.82
$\eta_{pump}(\%)$	0.1	0.02	0.37	0.1	0.1	0.02	0.44	0.40	0.007	0.02	0.06	0.04

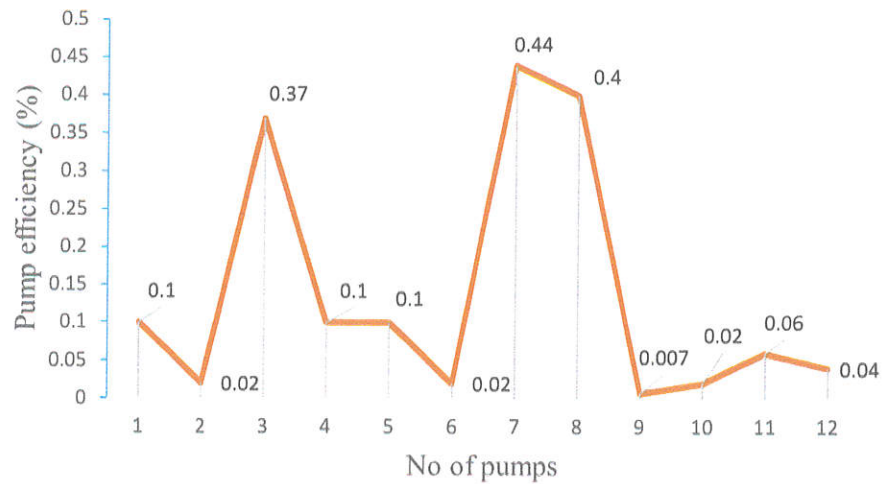


Figure 6-2 Efficiency of pumps

It can be seen from Table 6.11 and Figure 6.2 all efficiencies of pumps are below the recommended value. The recommended value of pump efficiency is 60 %. [14]

6.4.8. Overall efficiency

Using equation 6.8, overall efficiency of pump with motor was calculated. The overall efficiency was presented in Table 6.12.

Table 6-12 Overall efficiency of pump

Pumps	$P_{out}(\text{kW})$	$P_{measured}(\text{kW})$	$\eta_{overall}(\%)$
P_A	0.15	2.79	0.05
P_B	0.001	0.96	0.01
P_C	0.7	2.32	0.32
P_D	0.072	1.62	0.40
P_E	0.153	2.1	0.07
P_F	0.013	9.6	0.01
P_G	2.9	0.72	0.10
P_H	0.45	1.4	0.32
P_I	0.002	3.2	0.01
P_J	0.02	1.38	0.01



P_K	0.11	2	0.06
P_L	0.03	1.01	0.03

The overall efficiency of pumps and motors are (Table 6.12) below the recommended one. According to [14], average pump efficiency is 60 %. Therefore, this result show as there is mismatch between piping and pumping system.

6.5. Performance evaluation of motors

To check whether the factory motors are efficient or not, performance evaluation of motors was conducted. Energy-efficient motors should be considered to replace oversized and under loaded motors, instead of rewinding older, standard efficiency units, when major modifications are made to facilities or processes, as part of a preventive maintenance or energy conservation program.

6.6. Performance evaluations of pumps

All pumps used in the factory have the designed capacities of volume flow rate 3 m³/h to 40 m³/h and head 30 m to 45 m. The service time and operating hours of the pumps are 12 to 22 years and 465 to 8426 hours, respectively. The functions of factory pumps are to transfer water, fuel oil, sulfuric acid and aluminum sulphate from one position to another position in the factory. In order to analyze energy performance of the pumps with their motors, data must be collected first from nameplate and direct measurements.

6.7. Identified energy conservation opportunities

Based on the above audit analyses conducted on motors, pumps, and motors and pumps, the following lists of energy conservation opportunities are identified in addition to the housekeeping measures.

- Motors $M_A, M_B, M_D, M_E, M_F, M_H, M_J$ and M_K are working with 0.66, 0.62, 0.48, 0.53, 0.52, 0.50, 0.49 and 0.53 load factors with reference to the recommended load factor (i.e.40)
- Use high-efficiency motors
- Ensure voltage level and balance
- Although all the factory motors have low power factor motors M_C, M_G, M_I and M_L are those with lower power factors (0.34, 0.38, 0.38, and 0.36) respectively.



- Size motors properly
- Leakages are observed in most pumps
- Use variable frequency drives
- Factory pumps efficiencies are low.
- Shut down idling motors
- Almost all pumps have low efficiency
- Use advanced motor control
- Avoid rewinding motors
- Replace V-belts with cogged or synchronous belt drives

6.8. Technical and economical evaluation of identified energy conservation opportunities.

6.8.1. Technical evaluation of improving pumps efficiencies

From the energy analyses conducted above, the efficiencies of almost all pumps are very low (Table 6.11). This implies that the factory pumps waste the mechanical power of the driving motors. These energy wastages are signs to give attention to the causes of wastages in detail and investigated measures must be taken to improve the energy efficiency of the pumps. Pumping systems run inefficiently when mismatch between the actual condition they are working on and their design capacities occurred. To take meaningful energy saving measures for above selected pumps, imbalance between the actual and design capacities should be conducted as follows.

$$\text{Imbalance for pump } P_A = \left(\frac{H_{\text{actual}} \times Q_{\text{actual}}}{H_{\text{design}} \times Q_{\text{design}}} - 1 \right) \times 100\% \quad (6.9)$$

Where:

H_{actual} = Measured discharge head = 4.27 m

Q_{actual} = Measured flow rate = 0.0034 m³/sec

H_{design} = Required discharge head = 40 m

Q_{design} = Required flow rate = 0.0014 m³/sec

By substituting the above data the imbalance will be

$$P_A = \left(\frac{4.27 \times 0.0034}{40 \times 0.0014} - 1 \right) \times 100\% \\ = 74 \%$$

It is possible to calculate by using the same step the imbalance percentages of pumps



Table 6-12 Imbalance percentage of pumps

Pumps	P_A	P_B	P_C	P_D	P_E	P_F	P_G	P_H	P_I	P_J	P_K	P_L
Imbalance (%)	74	99	85	80	72	98	75	56	99	98	66	99

These imply pumps may have a high bypass flow rate, or have a flow rate that varies from their best efficiency points. Such pumps can be prioritized for further analysis, according to the degree of imbalance or mismatch between actual and designed conditions. The degrees of imbalance for all pumps are very high. Hence, replacing the existing old and inefficient pumps with new and efficient pumps is the solution to improve energy management of the factory. Estimation of pump efficiency, head and volume flow rate are essential parameters which should be considered to replace the pumps.

6.8.1.1 Pump volume flow rate estimations

All Pumps operate at a volume flow rates of in between $0.252 \frac{m^3}{hr}$ up to $140.4 \frac{m^3}{hr}$ (Table 6.9). Thus, the replaced pumps flow rates should satisfy these conditions.

6.8.1.2 Pump head estimation

All Pumps operate at a head of 4.27 m, 3.38 m, 3.4 m, 9.1 m, 4.38 m, 4.25 m, 2.1 m, 9.10 m, 2.91 m, 2.35 m, 2.91 m, and 10.8 m (Table 6.10). For the compensation of other minor losses 15% margin is added on heads. Therefore, the heads will be 5.4 m, 4.5 m, 4.6 m, 10.3 m, 5.5 m, 5.4 m, 3.3 m, 10.3 m, 4 m, 3.5 m, 4 m and 11.9 m. Thus, the replaced pump heads will also satisfy these requirements.

6.8.1.3 Pump efficiency estimations

An average efficiency of pump is 60% [14]. Thus, the selected replaced pumps should also attain an efficiency of 60%.

6.8.1.4 Input power of motors

Input power of the motor is given by the equation:

$$P_{in} = \frac{g \times H \times Q \times \rho_{fluid}}{\eta_{meas} \times \eta_{average}} \dots \dots \dots (6.10)$$

Where:

P_{in} = Input power of the pump

η_{meas} = Measured efficiency of the pump

$\eta_{average}$ = Average efficiency of the pump



ρ_{fluid} = Density of the fluid

Q = Flow rate of the pump

H = Head of the pump (15% margin added)

g = Acceleration due to gravity

Therefore, input power for pump P_A is

$$P_{in} = \frac{9.81 \times 5.4 \times 0.0034 \times 1000}{0.825 \times 0.60} = 0.36 \text{ kW}$$

Based on the above it is possible to calculate for all pumps, which are 0.36 kW, 0.028 kW, 1.8 kW, 0.16 kW, 0.36 kW, 0.31 kW, 1.26 kW, 0.36 kW, 0.05 kW, 0.52 kW, 0.29 kW and 0.58 kW respectively. The above technical analyses indicate that as the input electric powers are decreased when the existing pumps are replaced with the new ones (refer to table 6.6 for existing pump value). Thus replacing the pumps are technically feasible energy conservation opportunities.

6.9 Economic evaluation

6.9.1 Saving analysis

From the results of the energy audit analysis performed, it is known that the energy is saved by replacing the existing pumps by relatively efficient pumps. The energy saving analysis is given by:

$$\text{Saved energy} = (P_{A(\text{old})} - P_{A(\text{new})}) \times P_{\text{operating hours}} \dots \dots \dots (6.11)$$

Where:

$P_{A(\text{old})}$ = Existing pump input power = 2.3 kW

$P_{A(\text{new})}$ = New pump input power = 0.36 kW

$P_{\text{operating hours}}$ = Pump operating hours = 7336 hrs.

So, by substituting the above data to calculate saved energy of pump B

$$\begin{aligned} \text{Saved energy} &= (P_{A(\text{old})} - P_{A(\text{new})}) \times P_{\text{operating hours}} \\ &= (2.3\text{kW} - 0.36\text{kW}) \times 7336\text{hrs} \\ &= 14,231.8 \frac{\text{kWh}}{\text{year}} \end{aligned}$$

Using the same step for the rest pump should be 5517.5 kWh/year, 1431.8 kWh/year, 6324.5 kWh/year, 9123.8 kWh/year, 65,771 kWh/year, 2,780.5 kWh/year, 5,815.5 kWh/year,



22,226 kWh/year, 3,749.7 kWh/year, 11,679.5 kWh/year and 1,733.5 kWh/year respectively.

So, the saved cost can be determined by multiplying saved energy by current energy cost that is 0.55 Birr/kWh.

$$SC = SE \times EC \dots\dots\dots (6.12)$$

Where:

SC – Saved cost

SE – Saved energy

EC – Energy Cost = 0.55 Birr/kWh.

By substituting the values into the above equation, we can get the saved cost of the pumps.

For pump P_A saving cost will be

$$\begin{aligned} SC &= SE \times EC \\ &= (14,231.8 \times 0.55) \frac{\text{birr}}{\text{year}} \\ &= 7,827.5 \frac{\text{birr}}{\text{year}} \end{aligned}$$

For the rest pumps, the saving cost will be 3,034.6 Birr/year, 787.5 Birr/year, 3,478.5 Birr/year, 5,018 Birr/year, 36,174 Birr/year, 1,529 Birr/year, 3,198.5 Birr/year, 12,224 Birr/year, 2,062 Birr/year, 6,423.7 Birr/year and 953 Birr/year respectively. The total saving cost for 12 pumps will be 82,710.3 Birr/year

6.9.2 Analysis of implementation cost

The cost of pumps is approximately 12,000 Birr. The payback period can be found by dividing the cost saved with the cost of pump. Adding 15 % additional cost on the direct average cost of purchasing the pump for transportation, installation and other related costs [14]. The cost of the pump will be:

$$\text{Cost of pump} = 1.1 \times \text{initial cost of pump} \dots\dots\dots (6.13)$$

$$\begin{aligned} CP &= 1.1 \times 15,000 \\ &= 16,500 \text{ Birr} \end{aligned}$$

For 12 pumps the total cost will be

$$= 16,500 \times 12 = 198,000 \text{ Birr}$$

6.9.3 Payback period

$$SPBP = \frac{CP(\text{implementation cost})}{SC} \dots\dots\dots (6.14)$$



Where:

SPBP = Simple payback period

CP = Cost of pumps

SC = saving cost

So, for pump A

$$\begin{aligned} \text{SPBP} &= \frac{198,000 \text{ Birr}}{82,710.3 \text{ Birr/year}} \\ &= 2.4 \text{ year } (\cong 28 \text{ Months for all 12 pumps}) \end{aligned}$$

The approximate lifetime of the pump is 10 years. Therefore: replacing all pumps are economically feasible energy conservation opportunities.

6.10 Technically feasible energy conservation opportunities

- Avoid leakage from pumps,
- Install the pumps within the room they are in need of,
- Replace motors which are working with very low load factors
- Correcting the power factors of motors
- Replace the old and inefficient pumps

6.11 Performance evaluation of air compressor with its motor

Compressed air systems are used extensively in industry to provide compressed air for pneumatic applications such as pneumatic actuating of valves and cylinders, factory dust collectors and for pneumatic motors. There are also several compressed air uses in industry that in most cases can be considered misuses, which includes applications such as product cooling and cleaning. The factory uses a multi-stage oil cooled rotary type air compressor and its motor is a three-phase AC induction. In order to analyze energy performance of the air compressor with its motors data must be collected from nameplate and measurements. Compressed air systems that transport compressed air within a network to perform various factory end tasks.

Assessing the efficiency of compressed air system to efficiency in performing the task that the compressed air is serving.



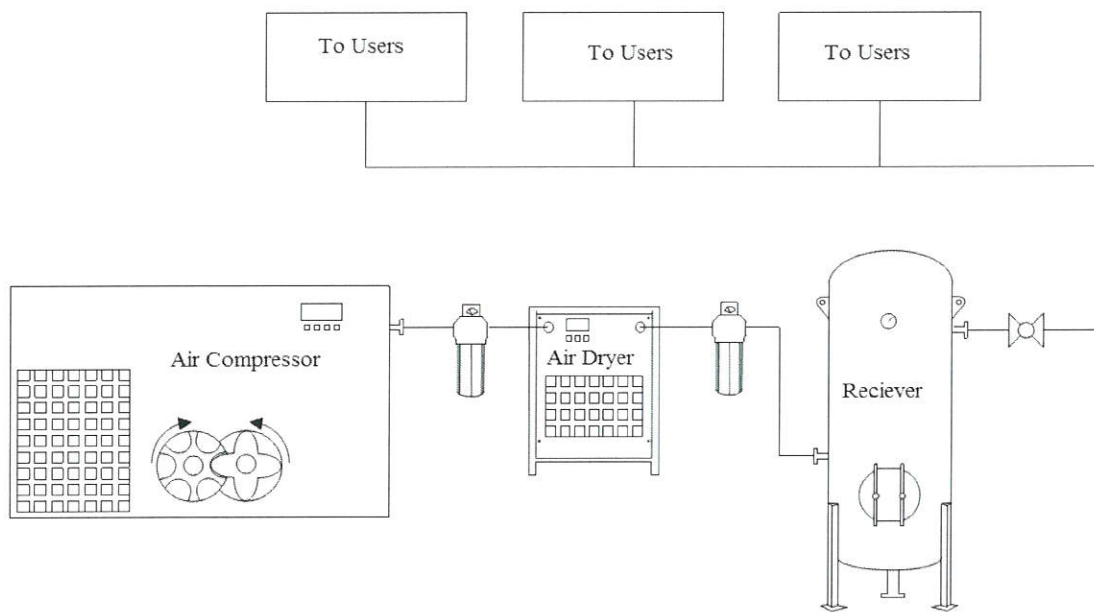


Figure 6-3 Factory air compressor systems [2]

6.11.1 Data collection

Data collection from the factory air compressor system and on its motors and compressor

6.11.2 Gathered data on motors

It includes nameplate current, voltage, power factor and measured line current, terminals voltage and input power using portable measuring instruments.

Table 6-13 Air compressor nameplate data

Compressor	Current(I)	Voltage(v)	Power(kW)	Efficiency (%)	$\cos \phi$
CM_1	58.5	380	30	86	0.81

Table 6-14 Air compressor measured data

Compressor	Operating hours	Current(I)	Voltage(v)	Power(kW)
CM_1	4000	44.5	383.2	21.5



6.11.3 Gathered data on air compressor

It includes measured inlet and outlet temperature of water used for cooling purpose, measured the time taken to fill 3 m³ of pressure vessel and measured inlet air temperature. In addition to measuring the above parameter the inlet and outlet air pressure are taken from the gage mounted on compressor. The collected data are presented in Table 6.15.

Table 6-15 Compressor measured data

compressor	Cooling oil at inlet(T ₁)	Cooling oil at outlet(T ₂)	Inlet pressure P ₁	Outlet pressure P ₂	Inlet temperature	Pressure risetime	Vessel volume	No of stage
C ₁	26°C	83°C	1bar	11bar	24°C	189sec	4m ³	5

6.11.4 Data analysis

In order to conduct the energy analysis and thereby to find the overall efficiency of air compressor with its motors the following parameters must be determine first.

- Nameplate input power of the motors
- Load factor of the motors
- Actual power factors of the motors
- Volume flow rate of the air
- Power gained by the air
- Mechanical power
- Compressor efficiency
- Overall efficiency

6.11.4.1 Nameplate input power of the motors

The nameplate input power of the motors of the compressor can be calculated using the following equation.

$$P_{\text{nameplate}} = \frac{I \times V \times \cos \phi \times \sqrt{3}}{1000} \dots\dots\dots (6.15)$$

Where

I = Nameplate current

V = Nameplate voltage

$\cos \phi$ = Nameplate power factor



6.11.4.2 Load factor of the motors

The load factor can be obtained by dividing the actual input power of the motor to nameplate input power of the motor. The expression used for calculating the load factor of the motors is given:

$$\text{Load Factor} = \frac{P_{\text{measured}}}{P_{\text{nameplate}}} \dots\dots\dots (6.16)$$

Where

P_{measured} = Input electric power (measured) = 21.5 kW

$P_{\text{nameplate}}$ = Nameplate input power = 31.2 kW

6.11.4.3 Actual power factors of the motors

The actual power factor of the motors is given by the following equation.

$$\cos \phi = \frac{P_{\text{measured}}}{I_{\text{meas}} \times V_{\text{meas}} \times \sqrt{3}} \dots\dots\dots (6.17)$$

Where

P_{measured} = Measured input power = 21.5 kW

I_{meas} = Measured current = 44.5 Amp

V_{meas} = Measured voltage = 383.2 volt

$\cos \phi$ = Actual power factor

6.11.4.4 Mass flow rate of the air

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

$$\dot{m}_{\text{air}} = \frac{\frac{(P_2 - P_1) \times V_{\text{vessel}}}{T_1 \times R}}{T_{\text{time}}} \dots\dots\dots (6.18)$$

Where

V_{vessel} = Volume of pressure vessel

T_{time} = Time taken to rise the pressure in sec

T_1 = Inlet air temperature

R = Universal gas constant (287)

$\dot{m}_{\text{air}}$ = Mass flow rate of air

$(P_2 - P_1)$ = Outlet and inlet pressure difference



6.11.4.5 Power gained by the fluid

The power gained by the air is given by:

$$P_{\text{fluid}} = \dot{m}_{\text{air}} \times C_p (T_2 - T_1) \dots\dots\dots (6.19)$$

Temperature in terms of pressure given by:-

$$P_{\text{fluid}} = \dot{m}_{\text{air}} \times C_p \left[\left(\frac{P_2}{P_1} \right)^{\frac{k-1}{N \times k}} \right] - 1 \dots\dots\dots (6.20)$$

Take specific heat of air 1 kJ/kg⁰K and K=1.4

6.11.4.6 Mechanical power

Due to the absence of torque meter, it is mandatory to take the nameplate motor efficiency to calculate the mechanical power of the motors. Thus, the mechanical power of the motor is given by-

$$P_{\text{mecha}} = \frac{P_{\text{measured}}}{\eta_{\text{nameplate}}} \dots\dots\dots (6.21)$$

6.11.4.7 Compressor Efficiency

The efficiency of pump is given by Equation (6.22)

$$\eta_{\text{cpm}} = \frac{P_{\text{mecha}}}{P_{\text{fluid}}} \dots\dots\dots (6.22)$$

6.11.4.8 Overall efficiency

The overall efficiency of air compressor with its motors can be calculated by dividing output power (power gained by the air) to input power of the motor (electrical energy).

$$\eta_{\text{over}} = \frac{P_{\text{measured}}}{P_{\text{Fluid}}} \dots\dots\dots (6.23)$$

6.11.5 Results and discussion

Using set of equations the following parameters nameplate input power of the motors, load factor of the motors, actual power factors of the motors, volume flow rate of the air, power gained by the air, mechanical power, compressor efficiency and overall efficiency were presented in Table 6.16.



Table 6-16 Results obtained from air compressor

No	Parameters	Results	Set of equations
1	Input power of the motor (kW)	31.2	6.15
2	Load factor of the motor	0.69	6.16
3	Actual power factor	0.73	6.17
4	Mass flow rate of air (kg/sec)	0.031	6.18
5	Power gained by the fluid (kW)	34.5	6.19 and 6.20
6	Mechanical power (kW)	25	6.21
7	Compressor efficiency (%)	0.72	6.22
8	Overall efficiency	0.63	6.23

6.11.5 General comment of the energy performance of air compressor with its motors

With 69 % of load factor of the compressor motor, the overall efficiency of factory air compressor system is 63 %. According to [29] the optimum value of motor load factor is ranging from 60 to 80 % and power gained by the air for the centrifugal compressor is ranging 10 to 40 % of the input electric energy. Therefore, both compressor load factor and overall efficiency of the compressor are within the recommended range.

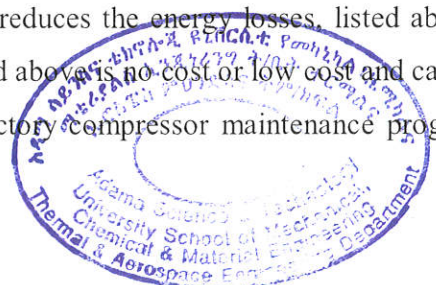
6.11.6 Energy conservation opportunities

From the audit analysis of the air compressor with its motor energy conservation opportunities are found.

- There is no regular air filter inspection program
- The compressor inlet duct is highly exposed to moisture and dust
- The dust collector compressed air line is usually let it open after completing its task.
- The compressed air distribution lines are long and have unnecessary bending

6.11.7 Technical evaluation of the energy conservation opportunities

According to detail energy audit of the air compressor system, the motor load factor and the overall efficiency of the compressor system is within the recommended range. Still have a window for improving the production and distribution of compressed air system. In accord with this fact, the result of energy audit conducted in this chapter revealed that there is a considerable energy savings potential in the compressed air system of the factory through improving the overall pumping efficiency, which reduces the energy losses, listed above. Hence, the technical feasibility analyses of all listed above is no cost or low cost and can be handled by routine maintenance program. The factory compressor maintenance program



must be including the following fact points in order to save energy loss from their air compressor.

- Shut off the dust collector compressed air line valve when compressed air is unneeded or delay bringing on additional compressed air until needed.
- Clean the area around compressor inlet duct from dirt and shrubs in weekly or daily basis.
- Relocate compressed air distribution lines as possible as short in length and minimizing number of bending.
- Regularly inspect the function of compressor air filter.



CHAPTER SEVEN

7 ENERGY ACTION PLAN

7.1. Introduction

Energy action plan is important to implement the suggested energy conservation managements. Based on this fact, the identified technically and economically feasible energy conservation opportunities are categorized in to short term, medium term and long-term action plans. Performing energy conservation managements based on their own action plan helps the organization to provide the savings gained from energy conservation managements with very short payback period to energy conservation managements with medium and long payback periods. To improve the energy efficiency of AMASSASCo, energy action plan for the identified recommended technically, economically and environmentally feasible measures should be designed.

7.2. Short term action plan

This kind of action plan is done on a regular basis and never less than once a year. This plan requires no capital investment or least improvement to avoid energy wastages and minimizing non-essential energy users and improving the system efficiency through improved maintenance program and can be implemented quickly without the need for additional studies to improve the system efficiency.

Table 7-1 Short term recommended ECOs and responsible body

No	Recommended ECOs	Responsible body	Energy action plan
1	Create valid awareness about energy utilization to the factory workers in formal and regular way	Management crews	Short term
2	Periodically blows soot from the boiler	Mechanical crews	
3	Regularly remove scale from boiler waterside	Mechanical crews	
4	Regularly remove scale from the water distribution lines	Mechanical crews	

5	Check proper functioning of steam traps once in a shift and replace the defective	mechanical crews	
6	Clean the boiler room from dirt	mechanical crews	
7	Control the excess air and damper position	mechanical crews	
8	Maintain the insulation of live steam lines	Mechanical crews	
9	Regularly clean the transformer fins from dirty	Electrical crews	
10	Removes shrubs around the transformer area	Electrical crews	
11	Install power measuring instrument for major electric appliance systems	Electrical crews	
12	Hang the fluorescent lamps to the proper place	Electrical crews	
13	Replace old and incandescent lamp	Electrical crews	
14	Turning off lights when not needed	Electrical crews	
15	Control compressed air distribution lines valves open when it needed	Mechanical & Instrumentation crews	
16	Regularly clean the electric motors from dirt	Electrical crews	
17	Calibrate instruments mounted on sulfuric acid and aluminum sulphate process	Instrumentation crews	

7.3. Medium term action plan

The medium term action plan is done once to achieve efficiency improvement through modifications of existing equipment's and other operations. This plan can be implemented at the factory level with small investment and are generally of low individual cost.



Table 7-2 Medium term recommended ECOs and responsible body

No	Recommended ECOs	Responsible body	Energy action plan
1	Clean the shell of the boiler at the mid of operation year	Mechanical and process crews	Medium term
2	Replace the water cooling tower pump	Mechanical crews	
3	Seal the pumps to avoid leakages	Mechanical crews	

7.4. Long term action plan

The long-term plan is done once to achieve efficiency improvement through innovation, planning and engineering input. The capital investments are required to be studied thoroughly while finalizing of the long-term action plan.

Table 7-3 Long term recommended ECOs and responsible body

No	Recommended ECOs	Responsible body	Energy action plan
1	Repair existing water treatment plant	Management crews	Long term
2	Replace low power factor motors with high power factor	Electrical crews	
3	Replace the oversized & under loaded motors with appropriate sized motors	Electrical crews	
4	Replace waste heat boiler tubes	All members	
5	Replace inefficient motors	Mechanical crews	

7.5. Energy action team

To supervise, monitor and report the energy utilization of the factory, Energy action team must be established in the factory. The tasks performed by this team include:

- Assess performance and setting goals,
- Look for any energy conservation opportunity improvements,

- Formulate action plans for implementing efficiency improvement,
- Coordinating the implementation of the action plan,
- Supervising and controlling the implementation,
- Evaluate and report performance.

This team must be led by an energy team leader or manager, and consists of all professionals who have brief knowhow about all energy related information of the factory.



CHAPTER EIGHT

8. CONCLUSIONS AND RECOMMENDATION

8.1. Introduction

Energy audit is a key step for decision -making in the area of energy management and it identify energy saving opportunities in study area to reduce energy consumption without compromising the productivity of an industry.

The energy performance of the factory was determined using different data collected by inspection, walk through audit, interviewing of the factory workers, referring to the nameplate of the major energy consuming systems, referring to the factory data record books and catalogs, and direct measurement using portable measuring instruments. In this study preliminary and detail energy audit of the energy systems of AMASSASCo were conducted, analyzed, and several energy conservation opportunities were identified. The study identified boiler with steam distribution system, electric motors, pumps, compressor as the major energy consuming systems of the factory. For these major energy systems energy conservation opportunities were identified and energy saving analysis and their economic evaluation were conducted as discussed below. In addition the major energy conservation opportunities are recommended with respective saved energy, cost of saved energy, implementation cost, and payback periods.

8.2. Conclusions

The factory uses thermal and electric energy inefficiently. As a result, this thesis dealt with the unwise energy consuming end use devices of AMASSASCo and attained its objectives. The end use devices were examined for their energy performance during the assessment time and energy conservation opportunities for the major energy consuming systems (Boiler, Pumps and motors) are identified. The major findings of the thesis as energy conservation opportunities in AMASSASCO include:

- Absence of awareness about energy management to the factory workers,
- Using untreated boiler feed water which results TDS in the boiler waterside,
- Combustion and boiler efficiency below the recommended values,
- Operation of motors with low load factors
- Using oversized in efficient pumps, and
- Using energy-consuming equipment's beyond their recommended lifetime even without maintenance.

These were discussed in this thesis based on their seriousness order in affecting the energy performance of the systems to take technically and economically feasible energy conservation opportunities.

By analyzing these data, many energy conservation measures are taken to increase the energy utilization performance of the factory by upgrading energy efficiencies of the end use devices in the factory.

8.2.1. Insulating boiler surface

The factory boiler is not well insulated. Due to this, energy is being lost from the boiler surface. To avoid the surface loss, insulating the boiler surface was taken as an energy conservation opportunities and the result of the analysis summarized as follows:

- Energy saved = 16.16 kW
- Cost of Energy saved = 164,385 Birr/year
- Implementation cost = 9,318.45 Birr
- Payback period = 1 month.

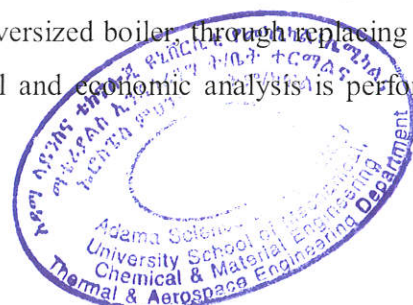
8.2.2. Repairing the existing water treatment unit

The feed water of the boiler use at the factory is inappropriately treated water due to the malfunctioning of the water treatment plant. Due to this, scale is deposited in the waterside of the boiler and results boiler shell energy loss of 133.7 kW. To avoid this, repairing water treatment plant and using mechanical cleaning equipment are the identified measures. The evaluation shows:

- Energy saved = 303.68 kW
- Cost of Energy saved = 3,089,184.8 Birr/year
- Implementation cost = 172,725 Birr
- Payback period = 1 months.

8.2.3. Replace the oversized boiler

The capacity of the boiler in use at the factory is 6 ton per hour at 15 bar whereas the demand of the factory is 4.3 ton per hour at different pressure, the maximum pressure being 1bar. Due to the oversizing, live steam is partly exhausted to the ambient; throttling is used to bring down 11 bar to 1 bar and less. This is wasting 811.3 kW of input energy of the boiler. For avoiding energy loss due to the oversized boiler through replacing the existing boiler with proper sized boiler, the technical and economic analysis is performed which resulted in



- Energy cost saving = 8,259,052 Birr/year
- Implementation cost = 6,428,125 Birr
- Payback period = 5 months

8.2.4. Control the excess air by reducing fan motor capacity

The power rating of the fan motor of the factory is 7.5 kW and it is functioning with 4.28 kW to supply excess air of 110 %, which is much far from the recommended value of excess air for furnace oil fired boiler (i.e. 15 %). Admitting excess air beyond the recommended value enables for exhaustion of large amount of sensible heat to the ambient through the chimney. For this, the economic analysis is done and results:

- Energy saved = 48.33 kW
- Cost of Energy saved = 491,636.9 Birr/year
- Implementation cost = 21,888 Birr
- Payback period = 1 months.

8.2.5. Insulating main steam distribution systems

Insulating main steam distribution systems of the factory is the basic measure and the feasibility study shows the following results.

- Cost of Energy saved = 57,692.56 Birr/year
- Implementation cost = 31,093.3 Birr
- Payback period = 7 months.

8.2.6. Replacing 12 pumps

This energy conservation opportunity is listed as a measurement due to the following results found after technical and economical evaluations.

- Energy saved = 14,231.8 kW
- Energy cost saved = 82,710.3 Birr/year
- Implementation cost = 198,000 Birr
- Payback period = 28 months

8.2.7. Implement No /Low Cost ECOs

The following housekeeping or low cost energy conservation opportunities help the factory substantially to reduce its energy cost. These are:

- Periodic remove scale from the boiler waterside
- Periodic removal of soot from boiler chimney
- Replacing the worn-out valves

- Insulate the bare steam lines
- Avoiding leakage from pumps
- Regularly check the proper functioning of steam traps and replace the failed ones
- Systematically control the compressed air distribution line valves
- Avoiding steam leakage from distribution system
- Cleaning all machines in the factory regularly
- Giving updated awareness on energy management to the factory workers

From these measures, the factory should have a clear image of its energy handling practice and take all the possible measures to become energy efficient and competent.

8.3. Recommendation

This thesis recommended many major energy conservation opportunities from the conducted detail energy audit for different system units and many housekeeping energy conservation measures to help the factory reduce its energy cost. Therefore, from the research findings it can be said that the factory should implement and monitor the recommended energy conservation opportunities based on the prepared action plan. In addition to these, it is better for the factory if it seeks advice from other energy audit teams to get benefit and become market competitive.

8.4. Future work

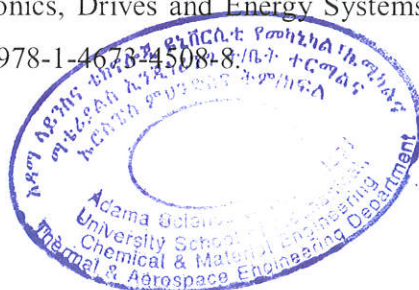
For the future, the factory should take the following points:

- Annual energy auditing should be carried out for finding energy conservation opportunities.
- Implementation of suggested energy conservation means should be done.
- The factory should establish energy management team for proper utilization and management of its energy.



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APPENDIX A

MEASURING INSTRUMENTS USED (audit time)

- Vernier Caliper
- Tape rule (Meter)
- Dual K type Thermometer
- Portable Combustion Analyzer
- Infrared Thermometer
- Bucket with Stopwatch

APPENDIX B

Item Description = steam system

Calculation Type = Insulation Thickness Table

Geometry Description = Steel Pipe - Horizontal

Bare Surface Emittance = 0.8

Ave. Ambient Temperature = 27.0 °C

Ave. Wind Speed = 2.5 m/s

Outer Jacket Material = All Service Jacket

Outer Surface Emittance = 0.9

Insulation Layer 1 = 850F Mineral Fiber PIPE, Type I, C547-07, 40.0 mm

Insulation Thickness Required For Surface Temperature ≤ 114.9 °C

Size	100°C	150°C	200°C	250°C	300°C	400°C	500°C	600°C
15	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
20	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
25	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
32	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
40	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
50	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
65	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
80	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
90	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
100	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
115	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
125	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
150	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1
175	Bare	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1	Layer 1

