



ENERGY AUDIT OF SEBETA ALCOHOL AND LIQUOR FACTORY

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December 2011

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A thesis submitted to the school of Graduate Studies of Addis Ababa Institute of Technology in Partial fulfillment of the requirements of the Degree of Masters of Science in Mechanical Engineering (Thermal Engineering Stream)

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ACKNOWLEDGMENT

Thanks and praise to the Almighty GOD!

I gratefully acknowledge my thesis advisor Dr.Ing. Edessa Dribssa, for his generous support, endless motivation, creative ideas, suggestions and serious follow-up greatly contributed to my thesis work.

I would like to thank also my co-advisor Ato Lelissa Daba for his momentous support in many aspects to accomplish my thesis work.

I pull-out my gratitude to all Sebeta Alcohol and Liquor Factory workers who have devoted their time to give me all necessary information and valuable data for this thesis (particularly Ato Amdie Wubeneh production head of SALF).

Thanks go also to all members of Mechanical Engineering Department of Addis Ababa Institute of Technology provided me measuring instruments from the department and wrote a letter to Sebeta Alcohol and Liquor Factory to get the necessary data for this work.

I am also grateful to my family and friends for their love, encouragement, and support.

At last, but not least, my sincere admiration goes to my friend Tadege Mihretu who has always been with me.

Abstract

Sebeta Alcohol and Liquor Factory is one branch of National Alcohol and Liquor Factory which uses light oil as the only energy source to generate steam for all end use devices which consume steam for their function. Fuel and electricity bills clearly indicate as the energy consumption patterns of the factory end use devices are variable from month to month due to many reasons including seasonal changes. The nine energy systems of the factory were inspected to identify ECOs and major energy consuming systems of the factory. Out of the nine energy systems boiler, distillery columns, and pumps and their prime movers were found to be major energy consuming systems.

The appropriate 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 which can lead SALF to good results in proper utilization of energy. The proposed ECOs are based on the analyses of wasted costs, saved costs, implementation costs, payback periods, and the best available technologies (BATs) on the market. These analyses allow to find inefficiencies and to propose improvements which would enable the factory a significant reduction of the energy bills and the environmental impact.

Using the collected data audit analysis of furnace oil, combustion performance of the furnace and property of steam were investigated. During the audit analysis the causes for the efficiency loss of the boiler were identified. From the results obtained in the audit, excess air admitted which is greater than the recommended value of 15%, absence of appropriate boiler maintenance, improper water treatment, absence of automatic blowdown control system which leads to excessive blowdown, and mismatch of steam supply and demand in the factory are some of them. Energy conservation measures suggested among various ECOs identified are:

- ❖ Installing double pipe heat exchanger to the distillery columns to extract heat from the effluent. For this 88,200.00 birr is needed to be invested as implementation cost and can be returned within 2 months and also gives 381,745.25 Birr/year benefits by saving 43.076kW energy.
- ❖ Repairing boiler feed water treatment plant with implementation cost 172,725.00 Birr to have a benefit of 257,446.18 Birr/year from 29.05 kW/year saved energy. The return time for this ECM is 6 months.

- ❖ Replacing motors (alcohol transferring pump motor from rectification column to temporary storage condenser feed water pump motor). For these an average of 11,000.00 Birr is needed as implementation cost and can be returned within 8 months and 1.68 years respectively. The total benefit gained from these measures is 23,662.29 Birr/year.
- ❖ Insulating boiler surface to avoid radiation and convection loss from the surface which is relatively very hot than the ambient temperature. For this measure 30583.82 Birr implementation cost is needed and 50,185.53Birr/year. The payback period will be 1 month.
- ❖ Insulating distillery surfaces. To conduct this measure 4097.21Birr is needed with return time of 1 month.
- ❖ Insulating steam distribution pipe lines to the distillery columns. To perform this, 43,346.34Birr is needed and returned within 7 months.

In addition to these, there are also many housekeeping ECMs which can be done with no or low cost by the factory workers.

Acronyms

AAFR	Actual air fuel ratio
AG	Alcohol Grade
AMR	Alcohol Meter Reading
A	Area
atm	atmosphere
P_R	Rated power
η_{comb}	Combustion efficiency
EC	Cost of electricity
CE	Cost of energy
CF	Cost of fuel
CP	Cost of pumps
C_{ele}	Cost of one kWh in Birr
$A_{C_{ele}}$	Annual cost due to lower electricity energy intensity
A_{C_f}	Annual cost due to lower efficiency of fuel energy intensity
DEI_{ele}	Difference of electricity intensity
DEI_f	Difference of fuel energy intensity
ECOs	Energy Conservation Opportunities
ECMs	Energy Conservation Measures
EIs	Energy Intensities
EA	Excess air
FAPC	Factory Annual Production Capacity
HVAC	Heating, Ventilation, and Air Conditioning system
GCV	Gross Calorific Value
IEO	International Energy Outlook
IEA	International Energy Agency
ISc	International Scenario
LF	Load factor of motors
$P_{meas.}$	Measured electric input power
MEC	Monthly Electric Cost

MFC	Monthly Fuel Cost
MFEI	Monthly Fuel Energy Intensity
η_m	Nameplate efficiency of motors
NALF	National Alcohol and Liquor Factory
NRDC's	Natural Resource Defense Council's
NCV	Net calorific value
η_{oa}	Overall efficiency of motors and pumps
PCA	Portable combustion analyser
η_p	Pump efficiency
H	Pump head
SC	Saved cost
SE	Saved energy
SALF	Sebeta Alcohol and Liquor Factory
SPBP	Simple payback period
T	Temperature
TAFR	Theoretical air fuel ratio
η_{th}	Thermal efficiency
WEO	World Energy Outlook

Symbol

g	Acceleration due to gravity
I	Current
ρ	Density
η	Efficiency
h	Enthalpy
R	Gas constant
Q	Heat
γ	Humidity factor
kWh	Kilo Watt hour
$\dot{m}$	Mass flow rate
MW	Mega Watt
P	Pressure
ϕ	Relative humidity
C_p	Specific heat
t	time
$\cos\phi$	Power factor
V	Voltage
$\dot{Q}$	Volume flow rate

Subscripts

A	Absolute
alc	Alcohol
am	Ambient
at	Atmospheric
bs	Back surface of boiler
bd	Blowdown
comb	Combustion
cs	Cylindrical surface of boiler
dist	Distillation
eff	Effluent
w	Feed water
filt	Filtration
fs	Front surface of boiler
f	Fuel
rect	Rectification
s	Steam
gs	Super heated steam
s	Surface
th	Thermal
ts	Total surface area of boiler
fg	Vaporization of water

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CHAPTER ONE

1. INTRODUCTION

1.1 World Energy Outlook

Energy plays a great role when ever man lives and works and at this time energy is considered to be the fundamental resource for human beings to live next to Air, Food and Shelter. In some parts of the world, it is nowadays difficult to live without air conditioning. The development and living standard of any country vary directly with the consumption of energy. The technological revolution of the last two centuries has fundamentally changed human life and has led to a progressive increase of energy requirements. Now days all stakeholders agree on the necessity to change the consumption trends, not through the reduction of the energy final uses (that would lead to a drop in the standards of living), but rather through the optimization of the same uses and the control of the wasted energy. Energy is the power up on which all activities depend. Energy affects everybody and every global economy. According to encyclopedia Britannica “All life flows from and depends on energy” [1]. Life cannot exist on earth, unless energy had been existed. Energy is necessary for human beings to pass through complicated natural, social, economic and political events. Energy consumption will increase with a rapid development in economy of the world. As a result, a high level of energy expenditure has been reached, which results in energy crisis and serious environmental impacts.

The consumption of energy has been greatly increased with the development of world from time to time. To deal on this, an international scenario on energy outlook and on the world market energy consumption rate was conducted in 2008G.C [2]. The ISc. of 2008 predicted the energy consumption from 2005 to 2030 and stated that the total world energy use rises from 135.4 trillion kWh in 2005 to 165 trillion kWh in 2015 and then to 203.7 trillion kWh in 2030. Although the world oil prices have been persist over the long run, yet global energy demand grows rapidly. Fossil fuels (liquid fuels and other petroleum, natural gas and coal) are expected to go on supplying much of the worldwide energy use. As reported by the IEO 2008, the average world oil prices of every year have been higher than that of the previous year. This shows that the energy consumption will increase from time to time with the economy and will continue growing as the populations will go on expanding, but the persisting high prices for oil and natural gas would not stop the world energy consumption. The growing world energy consumptions do not stop with price increment only rather,

challenges related to carbon emission and other environmental impacts will rise up. So, without discouraging economic and social developments of the world, different scenarios should be taken in different times.

The 2009 edition of the World Energy Outlook (WEO) was released on 10 November and it provides updated projections that take into account the implications of the global energy credit crisis, the economic slowdown and the recent fall in the prices of oil and other forms of energy. It also presents in depth analysis of three special topics. These are:

- Financing energy investment under post-2012 climate framework,
- Prospects (forecasts) for global natural gas markets, and
- Energy trends in Southeast Asia.

In this scenario these three mentioned topics were briefly analyzed in addition to previously amended energy outlooks with the previous time scenarios.

The 2010 edition of the World Energy Outlook (WEO) was released on 9 November and it provides updated projections of energy demand, production, trade and investment, fuel by fuel and region by region to 2035. It includes, for the first time, a new scenario that anticipates future actions by governments to meet the commitments they have made to tackle climate change and growing energy insecurity.

WEO2010 also puts the spotlight on several topical issues, including what more must be done and spent post-Copenhagen to limit the global temperature increase to 2°C and how these actions would impact oil markets; how emerging economies led by China and India will increasingly shape the global energy landscape. By considering these and other reasons, substitution of nonrenewable energy sources with renewable ones which are environmental friendly and with worldwide engagements are considered in the international scenarios [3].

1.2 Energy Scenario in Ethiopia

Ethiopia's energy consumption is predominately based on biomass energy sources. Largest proportion of the population is heavily dependent on traditional sources of energy and very few people have access to modern energies. Traditional Energy Sources are Fuel wood, Charcoal, and dung which account for about 94% of the total energy consumption of the country and only the remaining 6% accounted for modern energy sources, mainly products of petroleum and electricity[4].

Petroleum product is the major part from modern energy and it is mainly used for transport sector. Per capita electricity consumption in Ethiopia is 28kWh [5] [34].

Ethiopia has faced serious problems in energy supply and utilization. These include:

- The need to transform from traditional to modern energy sources which requires heavy investment in terms of foreign currency and domestic resources,
- The encouraged private sectors investment entails heavy investment burden in the energy sector,
- The continued destruction of forestry resources for firewood has resulted in environmental problems, loss of productivity and ecological imbalance,
- Increasing scarcity and cost of household fuels, particularly firewood increased stress on women and children who usually are supposed to collect fuel,
- Traditional energy consumption in Ethiopia is associated mainly with environmental problems,
- The cost of petroleum imports has brought worsening impact on Ethiopia's trade balance and foreign exchange availability,
- Low efficiency of energy utilization in all sectors,
- The agricultural sector is still at primitive stage and highly dependent on animate power,
- Lack of access and/or unavailability to modern energy sources in rural areas, etc....

Table 1-1 Exploitable energy potential of Ethiopia [5]

No.	Energy resource		Exploitable Potential
1	Biomass [million ton/year]		
	i.	Woody	1120
	ii.	Agricultural residue + Dung	15-20
2	Hydro [MW]		45,000
3	Geothermal [MW]		5,000-7,000
4	Average solar per day [kWh/m ²]		5
5	Wind [m/s]		5-6
6	Coal [million ton]		320
7	Natural gas [TCF]		4

1.2.1 Why Energy Policy is required? [5]

Ethiopia has energy policy which was drafted in 1994 and latest sector policies. There are reasons to develop energy policy for one country. These include:

- To develop and utilize the country's energy resources on the basis of its overall development strategy;
- To assist other economic sectors to meet their development objectives by putting in place a clearly defined energy policy;
- To save scarce foreign exchange resources and to ensure that energy is efficiently utilized;
- To ensure reliable and secure energy supplies to cushion the economy from external and internal disruptions of supply as well as price fluctuations;
- To ensure that development of energy prices and to ensure economic profitability;
- To ascertain what energy technologies and equipment are appropriate for and compatible with the country's economic development needs, and
- To raise the efficiency of the energy sector and develop the necessary institutional and man power capabilities to undertake energy development programs.

The power sector policy has emphasized on the use of indigenous resource and renewable energy. A sustainable energy development is a high priority and this also has been addressed in the environmental policy of Ethiopia too. The document is comprehensive in all aspects. The policy needs only to update when it is feasible with understanding that it passes through the process of dynamism. The main objectives of Energy Policy of a country include:

- Ensuring sustainable (reliable, affordable and long lasting) supply of energy,
- Removing the bottlenecks inherent to energy resource development and utilization,
- Providing guidelines and strategies for the faster development and supply of energy,
- Ensuring a reliable supply of energy at the right time and affordable price,
- Giving priority to the development of indigenous energy resource,
- Increasing energy utilization efficiency and reducing energy waste,
- Ensuring that the development and utilization of energy is compassionate to the environment, etc...

1.2.2 Energy Resource Development Policy in Ethiopia [5]

Both traditional fuels and modern energy resources should be considered in Energy resource development of a country. Modern energy resource development includes:

- Hydropower will form the backbone of the country's energy sector development strategy as it is the country's most abundant and sustainable energy resource.
- Ethiopia's geothermal resources will be developed on the basis of their economic profitability.
- Solar and geothermal energies will be used, wherever possible for process heat and power generation.
- Ethiopia's wind energy resource is suitable for power generation and will be developed to provide shaft power for water pumping and irrigation.
- Coal will be developed and used as alternative fuel.

1.2.2.1 Household's energy Policy

Most people of our society belong to the lower living standard and as such use wood and cow dung to carryout household energy consuming activities such as cooking, lighting etc... and those who can afford use kerosene and electricity. To improve our household energy usage and take energy conservation measures, we should teach the community at large. This helps to achieve a balance between the supply and demand for household fuels.

1.2.2.2 Agricultural energy policy

Government's agricultural sector energy supply policy is designed to increase the supply of modern energy sources to the agriculture sector to reduce energy loss due to improper management.

1.2.2.3 Transport energy policy

Most cars in our country are old and hence their energy efficiency is poor. Besides, some of the streets and highways on which they run are not asphalted which contributes its own share in extra loss of energy.

1.2.2.4 Industrial energy policy

The industries and factories in our country fulfill their primary and secondary energy requirements from electric energy and fossil fuel. Most of the mechanical equipments used by these sectors are old that their energy performance is poor. Moreover, they have poor performance and need high running costs. The energy wastage, the rejected unburned fossil fuels, the environment pollution and frequent maintenance cost require attention.

Government's industrial sector energy policy focuses to:

- Ensure that industrial energy supply will be compatible with the industrial development of the country and
- Ensure the industrial energy use and supply will be based on economic and efficiency criteria.

1.3 Problem statement of the thesis

Most factories in Ethiopia have the problem of proper utilization of energy. They did not know their energy consumption patterns in well defined manner by performing energy audit. This is due to:

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

As a result of these facts, I selected one representative alcohol and liquor refining factory (*Sebeta Alcohol and liquor Factory* which is so old and has so many energy related problems) to conduct energy audit. The observed problems in the factory signify that it should conduct energy auditing. Hence this thesis is aimed at examining the energy consumption patterns of the factory and efficiencies of the major energy consuming systems thereby identifying energy conservation opportunities to save energy for the factory to make it more competitive in the market.

1.4 Objectives of the thesis

1.4.1 General Objective

The primary objectives of the thesis are examining the way energy is being used in SALF, and identifying energy conservation opportunities so as to come up with actions taken to minimize energy wastage and preparing an effective energy implementation action plan.

1.4.2 Specific Objectives

There are also basic and essential specific objectives of the thesis. These include:

- General examination of work place including the physical condition of the factory, its process, occupancy time and energy consumption pattern.
- Clearly identifying the types and cost of energy used by the factory
- Understanding how energy is being used and possibly wasted
- Indicating better energy conserving opportunities by assessing the efficiency of its energy consuming devices.
- Examining energy consuming systems of the factory so the improvements can be quantified in terms of both energy and cost and obtain the sankey diagrams
- Identifying and analyzing improved operational techniques and / or new equipments that could substantially reduce energy use and which ones are cost-effective
- Evaluating economic and technical practicability of opportunities and recommending the feasible measures
- Preparing an energy action plan
- Increasing the profitability of industry by saving energy

1.5 Methodology

To do the thesis, the following method is used:

1. Literature review on alcohol production process and energy audit
2. Gathering data and analyzing it with preliminary audit, critical analysis of papers
3. Conducting introductory meetings, audit interview, walk through tour with relevant managers by establishing work relation with industry management

4. Conducting direct energy measurements by using portable measuring instruments
5. Performing desktop analysis on collected data
6. Identifying energy conservation opportunities by:
 - Performing technical evaluation
 - Performing economic evaluation
 - Calculating payback periods
7. Obtaining a list of energy conservation measures

1.6 Literature Review

Energy audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. It is the process of assessing the way energy is being used and possibly wasted in industries, factories, energy consuming systems, machines, etc... and if wastage is found, it takes corrective measures to minimize the wastage. Minimization of energy wastage is done by finding better way of meeting the energy demand.

As per the Energy Conservation action of 2001 [10], Energy Audit is defined as “the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption”.

Energy audit is one of the first tasks to be performed in the accomplishment of an effective energy cost control program. An energy audit consists of a detailed examination of how a facility uses energy, what the facility pays for the energy, and finally a recommended program for changes in operating practices or energy consuming equipment that will cost-effectively save money on energy bills.

Saving money on energy bills is attractive to business, industries and individuals alike. Customers, whose energy bills use up a large part of their income and especially those customers whose energy bills represent a substantial fraction of their company’s operating costs, have a strong motivation to initiate and continue an ongoing energy cost control program. No-cost or -cost operational changes can often save a customer or an industry (10 – 20)% on utility bills, capital cost programs with payback times of two years or less can often save an additional (20 – 30)%. In many cases these

energy cost control programs will also result in both reduced energy consumption and reduced emission of environmental pollutants.

Energy audit is sometimes called an energy survey or an energy analysis, so that, it is not in a weak position (hampered) with the negative connotation of an audit.

The energy audit is a positive experience with significant benefits to the business or individual. An energy audit is a technique for identifying energy losses, quantifying them, estimating conservation potential, evolving technological options for conservation and evaluating techno- economics for the measures suggested.

Energy Audit gives a positive orientation to the energy cost reduction, preventive maintenance and quality control programs which are vital for production and utility activities. Such an audit program will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, identify energy conservation technologies, retrofit for energy conservation equipment in industries, factories, households, etc...

For the audit to have the maximum value, it should address and express in quantified ways:

- Examination and evaluation of the energy efficiency of all energy consuming systems, processes and equipment (including energy supply and the building envelope)
- Indication of process management inefficiencies with negative impact on energy consumption.

The type of Energy Audit to be performed depends on:

- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.

- i. Preliminary audit
- ii. Detailed audit

1.6.1 Preliminary Audit [10] [19]

Preliminary energy audit is a relatively quick exercise to:

- Establish energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely (and the easiest areas for attention

- Identify immediate (especially no or low-cost) improvements or savings
- Set a 'reference point'
- Identify areas for more detailed study measurement

Preliminary energy audit uses existing, or easily obtained data. The preliminary audit alternatively called a simple audit, screening audit or walk-through audit which is the simplest and quickest type of audit. It involves minimal interviews with site operating personnel, a brief review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and identify glaring areas of energy waste or inefficiency.

Typically, only major problem areas will be uncovered during this type of audit. Corrective measures are briefly described, and quick estimates of implementation cost, potential operating cost savings, and simple payback periods are provided. This level of detail, while not sufficient for reaching a final decision on implementing proposed measures, is adequate to prioritize energy efficiency projects and determine the need for a more detailed audit.

1.6.2 Detailed Audit [19] [20]

A wide ranging audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and costs. It considers all the equipments that use available energy in the factory and performs energy cost saving calculations.

In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges.

This type of audit will be able to identify all energy conservation measures which are appropriate for the facility given in operating parameters. A detailed financial analysis is performed for each measure based on detailed implementation cost estimates (site-specific operating cost savings, and the customer's investment criteria).

Detailed energy auditing is carried out in three phases: Phase I, II and III.

Phase I - Pre Audit Phase

Phase II - Audit Phase

Phase III - Post Audit Phase

1.6.2.1 Phase I—Pre Audit Phase

In the first phase, data from the energy bills is analyzed in detail to determine what energy is being used and how the use varies with time. The main purposes of conducting pre audit phase in energy auditing include:

- Resource Planning,
- Organize instruments and timeframe,
- Familiarization of process/ plant activities,
- First hand observation and assessment of the present level of operation and practices,
- Orientation, awareness creation,
- Issue questionnaire for the department,
- Informal interview with energy manager or Plant Manager,
- Building up cooperation (conduct of brief meeting or awareness programme with all divisional heads and persons concerned),
- Collecting the necessary data, and
- Performing walk through audit.

1.6.2.2 Phase II—Audit Phase

Once all of the basic data have been collected and analyzed, the audit team should tour the entire facility to examine the operational patterns and equipment usage, and should collect detailed data on the facility itself as well as on all energy using equipment.

The facility inspection is an important part of the overall audit process. Data gathered on this tour, together with an extensive analysis of this data will result in an audit report with possible implementation plan.

After the plant survey, the audit team must develop an energy balance to account for the energy use in the facility. Once all energy uses have been identified and quantified, the team can begin analyzing alternatives. Detailed studies to establish and investigate energy and material balances for specific plant departments or items of process equipment are carried out.

The final step of phase two is the audit report which recommends changes in equipment, processes or operations to produce energy cost savings. This phase is the main step of energy auditing activity which includes:

- Conduct of detailed measurements,
- Analysis of energy use/desk top analysis,
- Historic data analysis, baseline data collection (primary data gathering),
- Analyzing the energy and material balance for the areas,
- Energy and material balance & energy loss analysis,
- Design operating data and schedule of operation,
- Cost benefit analysis (annual energy bill and energy consumption pattern),
- Measurements: energy generation and distribution system survey, with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data,
- Identification & consolidation energy conservation measures,
- Conceive, develop and refine ideas,
- Review the previous ideas suggested by energy audit if any,
- Assess technical feasibility, economic viability and prioritization of energy conservation options for implementation,
- Prioritize by low, medium, long term measures,
- Documentation, report presentation, etc...

1.6.2.3 Phase III – Post-audit Phase

After the energy consumption data has been collected and analyzed, the energy-related systems have been carefully examined, the ideas for improvement have been collected, and management commitment has been obtained, the next steps are to obtain company support for the program, to choose goals, and to initiate for action implementation and following the identified opportunities with their action plan.

Assist and implement energy conservation measures and monitor the performance are the main goal of this phase.

- Action plan, Schedule for implementation
- Follow-up and periodic review

1.7 Organization of the thesis

This thesis research is organized in 10 chapters which all are necessary in energy audit report arrangements.

Chapter one discusses the need of conducting energy audit, the general and specific objectives of the research, meaning of energy audit, types of energy audit and methodology.

Chapter two presents brief introduction of *Sebeta Alcohol and Liquor Factory* including: its location, weather condition, organizational structure, staff profile, operating hours, utility systems of the factory, and lists of major energy consuming equipments.

In chapter three, alcohol production process and the necessary energy inputs of the process are discussed.

Chapter four deals on the twelve months factory energy bill analyses, energy consumption patterns of benchmarks, energy intensities, comparison of energy intensities of SALF with the benchmarks.

Chapter five presents the preliminary energy audit, inspection of the major energy systems of the factory to discover no/low cost energy conservation opportunities (ECOs) and major energy requiring systems of the factory that required detail energy audit analysis.

In chapter six, the detailed energy audit of the boiler is discussed to discover its energy conservation opportunities and to take the feasible energy conservation measures.

Detail energy audit of the distillery system was discussed in chapter seven in order to investigate its energy conservation opportunities.

Chapter eight presents the detailed energy audit of motors, pumps, and motors and pumps. Motors with greater than 5kW (most of the time the cut off value) rated power are discussed.

In chapter nine, technically and economically feasible energy conservation opportunities are summarized and categorized in short, medium and long term ECMs.

In chapter ten, conclusions and recommendations of the research are presented. In addition the thesis contains references and appendixes.

CHAPTER TWO

2. INTRODUCTION TO SEBETA ALCOHOL AND LIQUOR FACTORY

2.1 Introduction

Sebeta alcohol factory is a governmental organization which produces potable fine alcohol. The factory was initially established in 1914 by a Greece citizen called Madam Anafi in Addis Alem 67 km from Addis Ababa. After a few years of establishment, it starts production of alcohol and continues until 1936. From 1936 to 1941 the factory ceased its function due to the invention of Ethiopia by Italy and its new form establishment at Sebeta within an area of 27,580 square meters. In 1941 W/o Shewareged Gedlie takes it from Etege Bete-Resit with rental fee and used it until 1943. After 1943 onwards another Greece person called Athnassios Zouvelos took it with rental fee of 1500Birr and changed its internal structure from traditional to modern way and used it till 1968 for 24 years. During his ownership time, he did many activities on the factory structure. These include:

- Erection of the boiler which needs wood as input
- Erection of Distilleries
- Preparation of wine storage tanks(wells) from cement
- Construction of Distillery house
- Erection of bottle washing and filling machines (in 1967), etc...

The function of the factory stopped for four consecutive years (from 1968 to 1972) when Zouvelos died in 1968. From 1972 to 1977 an Ethiopian citizen called Mr. Berhanie G/Medhin took it and used it till 1977 with fee. During his time of usage molasses storage house was constructed to change the previous used crops as a sources material for alcohol production to molasses. After 1977, it is changed in to state owned organization [6] [Interview].

2.2 Weather Condition

Geographical Location of Sebeta Alcohol and Liquor Factory is located at 25Km south west of Addis Ababa with an elevation of about 305 meter above sea level. The climate of the area is typical of the tropical wet and dry class, which is characterized by three temperature periods:

- The cool, dry period at the time of low sun or winter,

- The hot, dry period just proceeding the rainy season, and
- The hot, rainy period.

Days have somehow uniform temperature throughout the year. The pattern of rainfall is bimodal and at average 1000 mm per year.

2.3 Organizational Structure

Sebeta Alcohol Factory is administrated under National Alcohol and Liquor Factory that have four alcohol and liquor factory branches namely Mekanissa Alcohol Factory (MAF), Maichew liquor factory (MLF), Akaki Alcohol Factory (AAF) and Sebeta Alcohol and Liquor Factory (SALF). The factory has three departments namely production, logistics and human resource development and administration departments. The organizational structure of the factory is summarized as follows [6].

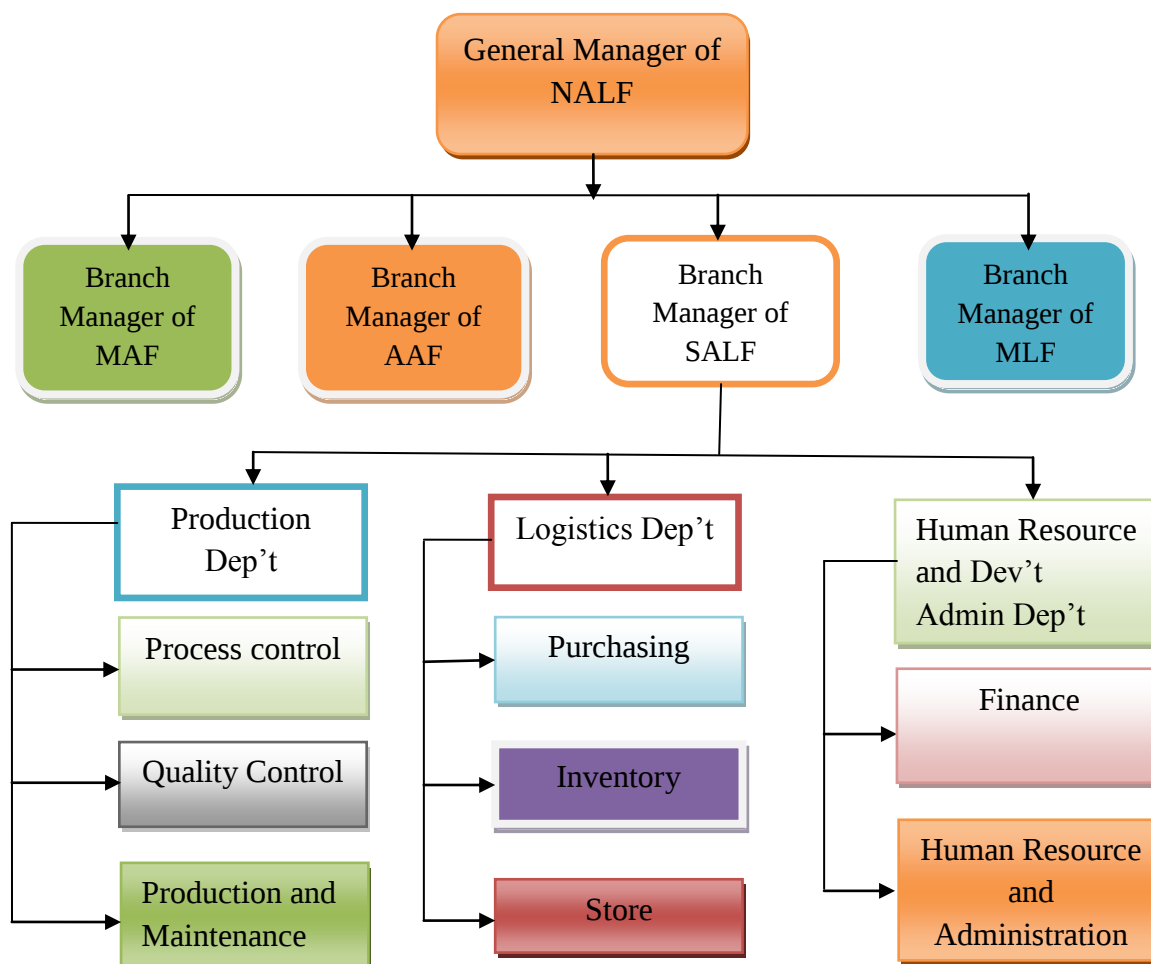


Figure 2.1 Organizational structure of SALF

2.4 Staff Profile

The total number of employees of the factory is 209, out of which:

- 126 are permanent employees including the administrators, and
- 83 are temporary laborers' (this is the maximum number seen in my study time) and this number varies based on the day today activity of the factory).

SALF is lead with a branch manager under NALF and under it there are six departments, statistician and secretaries. The six departments include: Total personnel service department, finance department, maintenance department, property section, alcohol preparation department, and liquor preparation department.

The distribution of the permanent workers in each department depends on the need of the factory. Based on this, the employee distribution is 31 workers in total personnel department, 4 workers in finance department, 15 workers in maintenance department, 27 in alcohol preparation department, 40 in liquor preparation department, 5 in property section, 1 statistician, 2 secretaries, and 1 branch manager. Temporary workers are needed with different number within each working day of the factory based on the activities performed in each section of the factory. Most of the time, more temporary workers are needed in liquor preparation sections.

2.5 Operating Hours

The factory operates throughout the year throughout the day with three shifts.

- Morning shift (from 8:00 AM to 4:00 PM)
- Afternoon shift (from 4:00 PM to 16:00 PM) and
- Night shift (from 16:00 PM to 24:00 AM) with 8 hours operating times for each shift.

2.6 Utilities

The utility systems which the factory uses are:

1. Steam generation and distribution utility systems: The major fuel supplier of the factory is National Oil Company (NOC) and its main use is to produce steam in the boiler. To produce steam by using furnace oil and to distribute it for the enduse devices, these utilities are essential.

2. Water distribution utility systems: The source of much amount of water used in SALF is ground water in the factory compound and a little amount from Sebeta town. The factory consumes water to:

Hence; to have these functions in the factory from water, the presence of water distribution utility systems is must.

3. Electricity utility systems: The factory uses electricity for lighting and to operate electrical appliances (such as pumps motors, air compressor fans, computers, mobiles for charge) etc. in the factory. So, the factory should have the necessary electricity utility systems.

2.7 Major Energy Consuming Equipments

Steam is generated by using the factory Boiler and most of it is consumed by distilleries. And other major energy consuming equipments in SALF are motors. From the main consuming equipments, the following are mentioned.

❖ Distillery columns:

- Distillation column,
- Filtration column, and
- Rectification column.

❖ Motors :- motors with rated power greater than 5 kW are included:

- Boiler fuel feed pump motor,
- Boiler feed water pump motor,
- Two submersible pumps,
- Alcohol transferring pump from temporary storage to liquor room/yeast sucking pump motor from yeast propagation tank to wine fermentation tanks,
- Water feed pump motor to bottle washing machine
- Compressor pump motor, and
- Condenser feed water pump motor.

CHAPTER THREE

3. ETHYL ALCOHOL PRODUCTION PROCESS

3.1 Introduction

The main source used in the factory to produce pure Alcohol is molasses which is by-product of sugar factories. The sugar content in the molasses is changed in to alcohol by the process of fermentation with yeasts. Even though the use of fermentation process for alcohol production was started in early period of human beings, it is revised in modern way in 19th century with the discovery of Liwis Paster. He discovered that as sugar has an alcoholic content and can be changed in to pure alcohol and other by-product compounds with the help of yeasts.

In our country Ethiopia pure alcohol can be produced in traditional as well as in factory level. During fermentation, different compounds will be produced. From these the main is pure alcohol which is the target of the factory. In addition to this aldehydes, acid and fusel oil which are unnecessary compounds. The amounts as well as the grade (purity level) of the alcohol produced depend on the efficiency of the fermentation process taking place [7]. So following the correct scientific method from the raw material till the well fermented wine transferred to alcohol distillery. To come up with solutions to procedural and technical problems in alcohol production process, SALF prepared a manual in the year 1986 E.C. by the employees of the factory. This again revised in the year 2001 E.C. During this time different methods and ways were revised to upgrade the fermentation process of alcohol production [6].

In SALF both potable and other technical alcohols are produced. The factory use cane sugar molasses as feed stock though there are various feed stocks (wheat, corn, grain sorghum, black strap molasses, sorghum cane, sweet potatoes, raw sugar, potatoes, pineapples, apples, etc...) which can produce much amount of alcohol. In alcohol production process in the factory, thermal and electrical energies are used in addition to other raw materials.

3.2 Ethanol production process

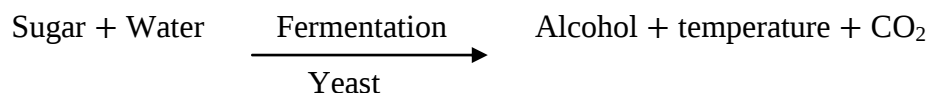
In industry level pure alcohol, ethyl alcohol and ethanol are identical terms. Ethanol can be produced from starch containing substances by fermentation with the presence of yeast in bio-chemical reaction. Bio-chemical reaction prepares the pure wine which is used as an input raw material for the distillery columns. The raw materials which are used in fermentation process of

alcohol include: molasses, yeast, nitrogen compounds, acid, antifoam, disinfectants (dison), and water.

There are determinant factors in fermentation process which need continuous follow ups to produce the required amount and quality of alcohol. These include:

- ✓ Way of using and treating the raw materials
- ✓ Way of using production instruments, materials and environmental cleaning, etc...

Ethanol production process can be expressed in scientific terms as follows:



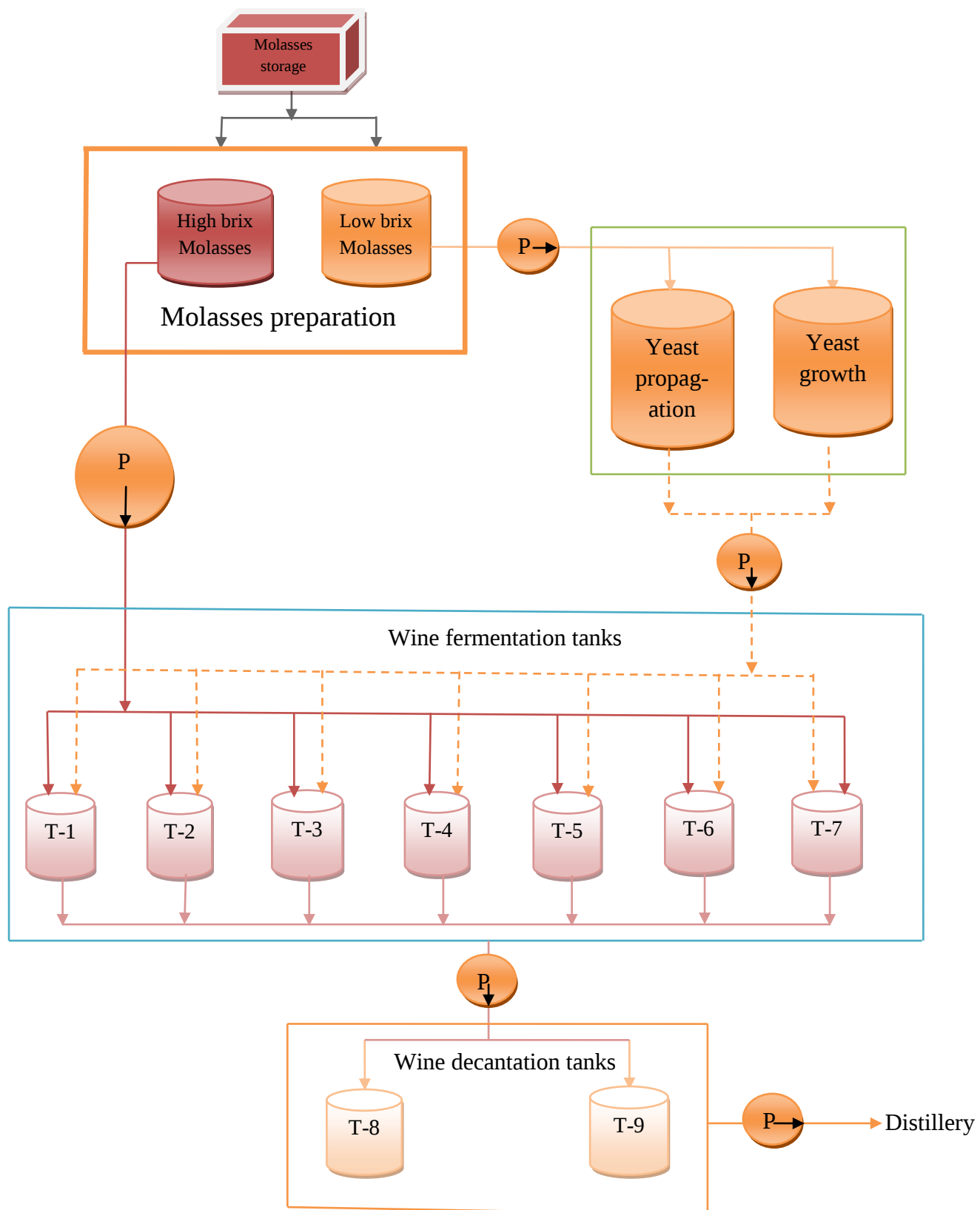


Fig.3.1 Wine fermentation process at SALF

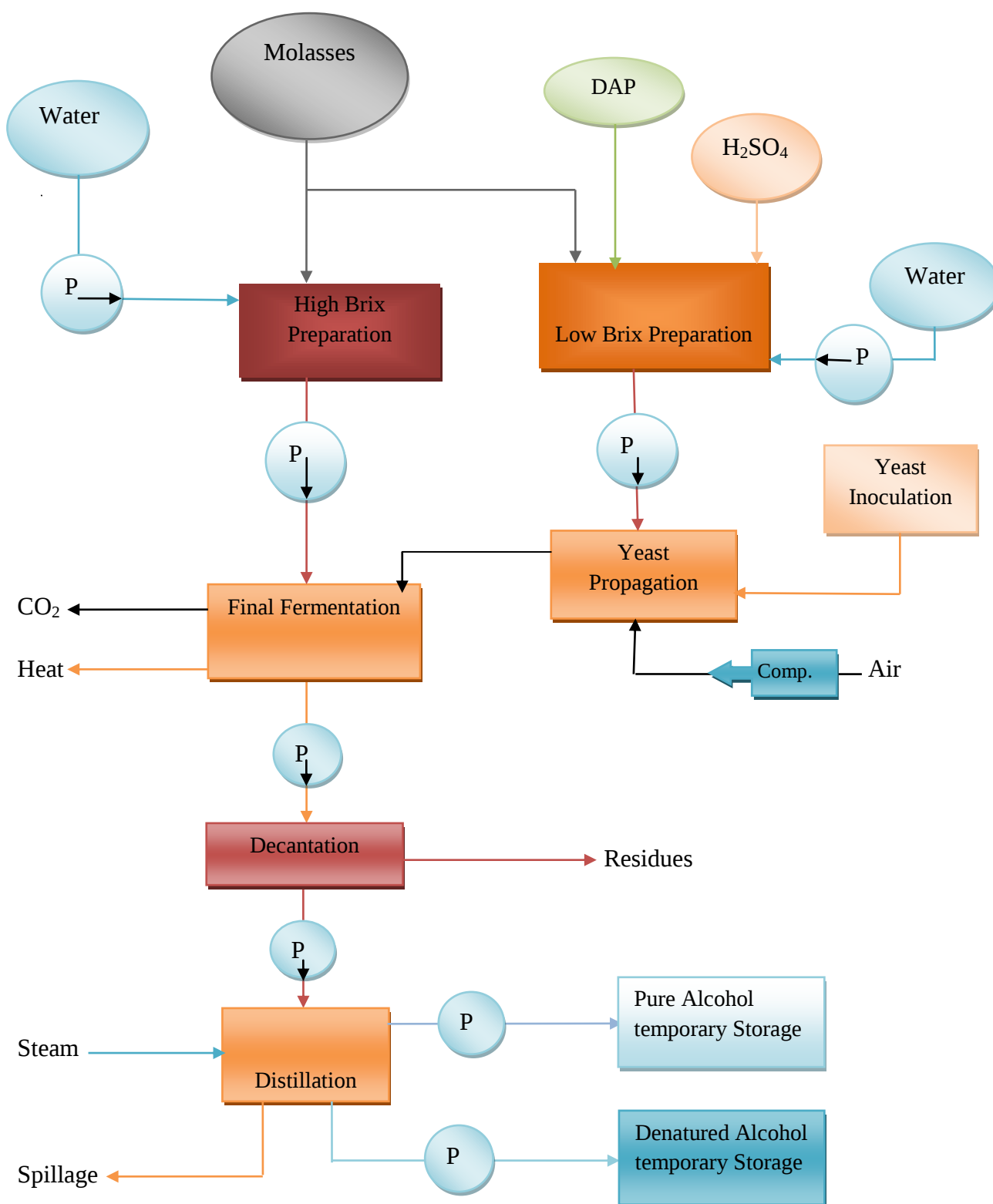


Fig.3.2 Pure Alcohol production flow chart

During this process taking housekeeping energy measurements (cleaning fermentation house, raw material stores, fermentation tanks, yeast propagation tanks, etc... regularly) are necessary to ensure the production capacity of the factory.

If the molasses is tainted with bacteria and wild yeasts;

- Amount of the produced pure alcohol will be reduced due to the formations of side compounds (formation of unwanted compounds from the input raw materials)
- Fermentation process will delay and continuity of the process will chop
- Stores will erode, holed and allow the entrance of bacteria and other microorganisms which affect the production process. To avoid such alike problems the following measure should be taken:
 - ❖ Cleaning the fermentation room regularly
 - ❖ Sterilize the yeast propagation tank up to 80°C
 - ❖ Avoid the wine residue by giving enough decantation period
 - ❖ Perfume the working environment with anti-biotic chemicals based on the scheduled program of the factory product controlling room
 - ❖ Taking care of leaking areas of wine tank, wine and molasses transferring pipes, etc...

Wine storage and cooling tanks should have their own specific cover. This is to prevent the entrance of freely floating bacteria in the environment into the storage wells. In addition to this it leads the yeasts to take place anaerobic condition which enables them to change the total sugar content in the molasses into pure alcohol. Another important advantage is that, it will reduce the amount of alcohol loosed due to evaporation.

Quality of raw materials and their way of handling are other areas which need great care. The raw material quality should be checked up by responsible persons during buying (e.g. whether the molasses contain the expected amount of sugar or not), transporting, storing, using (e.g. is there enough air movement in the fermentation tanks), etc...

3.3 Fermentation process controlling methods

Performing physical and chemical tests to check whether the wine reaches at good fermented stage or not and help to know at what stage the process is found and also what is its shortages.

Fermentation process controlling methods include molasses brix checkup, temperature of the process, fermentation period, microscopic checkup, wine odor, etc...

3.3.1 Molasses Brix

During fermentation process the sugar content of the solution should be measured within two hours gap consecutively. If the brix decrease, the sugar is in the process of changing in to alcohol and the remark is good. If not, we understand that the process is not in good condition. This may happen due to an abrupt temperature change.

3.3.2 Temperature

Due to high fermentation movement in the process, the temperature of wine will increase. To avoid this, wine tank should be cooled with cold water, unless it may lead the process to useless. Very slow as well rapid lift of temperature is not the sign of good fermentation process.

- ❖ If the increment of temperature is very slow:
 - Amount of yeasts transferred to fermentation is low
 - There is bacterial infection
 - Yeasts are very weak, etc...
- ❖ If the increment of temperature is rapid:
 - The sugar content of the molasses syrup is maximum
 - The entrance temperature of the molasses syrup to fermentation tank is high, etc...

3.3.3 Fermentation period

Another fermentation controlling mechanism is the time duration that the process takes. If the time is short, the process is fast and the reverse is true. When the fermentation process requires longer time than the normal time, one of the following might be happened.

- Either the number of yeasts is below sufficient or highly thick molasses brix is supplied
- Micro-biological infection may happen
- Environmental temperature decrease
- Selected type of yeast cannot perform their function properly, etc...

In other case, when the fermentation process requires very short time, one of the following might be happened.

- Less sugar containing molasses is supplied
- The environmental temperature may be maximum
- Selected types of yeast are doing their function actively, etc...

3.4 Alcohol distillation process from wine

In this process the well fermented and high alcohol containing decanted wine will be transferred to the distillery and evaporated with steam to produce pure alcohol. The main aim in this process is fulfilling the alcohol standard of the factory aimed to be produced. Separation of alcohol by distillation is done with three main processes which consume the most amount of steam generated in the factory. These are:

- Distillation process,
- Filtration process, and
- Rectification process.

Each process requires sufficient amount of steam energy based on their designed capacity to have good functions in the factory.

3.4.1 Distillation process

Distillation is the first act in which all alcohol containing compounds found in wine will be separated. It is the processes of boiling different mixtures, at different boiling points, in different columns and condensing the vapors in order to separate one from another by fractional distillation. Unnecessary compounds and fluid mixtures with low boiling point will be evaporated and condensed with their own boiling point. In addition to this, at the upper part of the distillation column there is a part called acidity column used to remove the separated unnecessary acidic compounds. Alcohol is highly volatile and has low boiling point in contrast with water. These properties make alcohol to be distilled easily from water and other compounds.

Fermented wine will be added at the top and steam will be supplied at the bottom part of the distillation column. Steam with high temperature goes up and cooled wine come down and heat exchanging will takes place between the two fluids through convection and evaporation of liquids

with low volatility will evaporate but not highly volatiles. These will remain within the residue. Though this is the fact, partial evaporation of these compounds will take place. Due to this the evaporated liquid has only (30% – 50%) alcohol content [Chemist interview]. Partially condensed liquid then transferred to the filtration column through transferring pipe and the process of transferring is called reflux. The major tasks done at this process are:

- ❖ Separate (30-50) % of alcohol from fermented wine and send it to the filter column for further purification.
- ❖ Send easily volatile acidic substances to fusel oil column to be distilled and condensed & then discharged in the form of denature.
- ❖ Discharge liquids free from alcohol and gaseous substances like SO₂, CO₂ and other solutions having lower boiling points from the bottom of the column.

3.4.2 Filtration process

The liquid transferred from the distillation column contains unnecessary high boiling point compounds [aldehyde, methanol, acid, oil, etc...] in addition to pure alcohol. Due to this, the fluid will be boiled up to 82°C by the supplied steam and the evaporated alcohol will be backed up to increase the alcoholic content and then transferred to the third column called filtration column [Inspection]. As a result, this process stage is determinant for the production of pure alcohol and needs maximum care starting from design to production. In this column aldehyde and other undesirable solutions are removed as effluent and the distilled alcohol is transferred to the rectification column.

3.4.3 Rectification process

The alcohol transferred from filter column is low in alcoholic concentration. It contains water and another high boiling point wild compound. To come up with good alcohol grade, boiling of the transferred alcohol is a must in rectification column. This column has different alcohol rotating stages which can supply heat to the process from repeated rotation of alcohol in the stages in addition to supplied steam to the column. During this, water and other wild compounds will be boiled and separated from pure alcohol as a result the strength of alcohol will increase to 96% which is acceptable standard.

After the alcohol reaches to the required alcohol concentration, it will not come back in to the rectification condenser rather transferred to the temporary storage and then to the permanent storages.

3.5 Instruments used in alcohol production process

There are many instruments which are basically needed in alcohol producing factories. From these: Alcohol meter, BAUME, Wine florometer, Flue gas analyzer, Power clamp, Thermometer, Meter, Caliper, and different gauges attached at different instruments. From these only BAUME and Wine florometer are present in SALF. From these some of them (which are not familiar) are discussed below.

3.5.1 Alcohol meter

This instrument reads temperature against grade of alcohol. When temperature increase, evaporation will increase and the alcohol content will decrease. Due to this fact, the grade of alcohol will decrease as temperature increases. As a result, the alcohol meter reads different alcohol grade values for different temperature values. The quality of alcohol produced will be controlled with the relation:

$$AG = AMR - (T^\circ - 15.56^\circ\text{C})K \text{ [Chemists interview and manual]} \dots\dots\dots (3.1)$$

Where:

AG= Alcohol grade [%]

AMR= Alcohol meter reading [%]

T° = Temperature of alcohol produced [$^\circ\text{C}$]

$K = 0.2$ (constant factor) [%/ $^\circ\text{C}$]

If $(96.0 \leq AG \leq 96.6)\%$, the alcohol produced has good quality.

Example:

$AG = 97.8\%$
 $T^\circ = 22.5^\circ\text{C}$ } Measured values taken from the factory laboratory during the study time

$$AG = 97.8\% - (22.5 - 15.56)^\circ\text{C} * 0.2\%/^\circ\text{C}$$

$AG = 96.412\%$ which is in between 96.0% and 96.6% . Therefore the alcohol produced is good.

When the range of AG is out of the above specified values; the product alcohol should be recycled to be corrected. Unless it fulfills, it is not used as a normal product.

3.5.2 Baume

Baume Scaled hydrometer is an instrument used to measure the brix of molasses syrup produced for fermentation. Depending on the densities measured by this instrument, the high and low brix molasses preparation will take place.

3.5.3 Flue gas Analyser

Flue gas analyser measures and calculates flue temperature, inlet or ambient temperature, net temperature, flue O₂ content, flue CO₂ content, flue CO content, combustion efficiency(gross or net), flue excess air and losses [Flue gas analyser manual]. Flue-gas analyser has three components:

1. Handset:
 - Display data from analyser
 - Operates analyser
 - Operates 20m away from analyser
2. Analyser:
 - Receives flue gases from probe
 - Removes water vapor and particles
 - Distributes gases to sensors
 - Exhausts gases to atmosphere
 - Prints data
 - Powered by battery or external supply
3. Gas probe:
 - Removes flue gases to analyser
 - Measures gas temperature
 - Operates 5m away from analyser

3.5.4 Power Clamp

Power clamp is an instrument which can measure the motors load. It can display motor load power, voltage, and load current simultaneously [Power clamp manual].

3.5.5 Wine Floro meter

This is another determinant instrument used in the factory to measure the amount of wine transferred from decantation tank to distillation column. Based on SALF standard an average 1400 l/h wine is supplied with an expectation of 8 – 13 liters of alcohol [Wine floro meter reading]. All expected alcohol is not pure rather both pure and denatured.

3.5.4 Reading gauges

These are different gauges in the factory system units [gauges of the boiler, distillery columns, pumps, temporary and permanent storage tanks, etc...] used to measure pressure, temperature, and flow rates.

3.6 Liquor preparation process

Pure alcohol produced in the factory and stored in the storages will transfer to the liquor preparation section to be changed in to liquor by the addition of different additives (essences) with different amount to have different types of liquors.

3.6.1 Methods of liquor preparation

At this time liquors are prepared in two main methods. These are:

1. By the process of distillation from different compounds which have different test and odor, and
2. By adding different essences with pure alcohol and blending with water. Liquors prepared in this method are called compound liquors.

The first method needs different sources, technologies, techniques, highly skilled human power in different areas, high surface area to the plant and high investment cost, etc....

The second method is less technical, less expensive, requires less investment cost, requires one source, etc... From these, the second method is easier than the first one in relative [7]. Due to these reasons, SALF uses the second method to prepare liquor.

3.6.2 Types of liquors prepared in SALF [7]

As it is mentioned above, SALF use pure alcohol (96% alcoholic concentration) to produce different liquors. Different types of liquors are produced from pure alcohol only by varying the additives ratio. Compound liquors prepared in such a way are grouped in to three categories.

3.6.2.1 Strong alcoholic drinks

There are different alcoholic drinks which are grouped under the strong category. These include Jin, Ouzo, Perno, Enatna Leji, Brandi, and Cognac.

3.6.2.2 Medium alcoholic drinks (sweet liquors)

Sweet liquors are also produced in SALF. From these some of them produced in SALF include Lome Liquor, Ananas Liqour, Apperative Liqour, and Supermint Liqour.

3.6.2.3 Low alcoholic concentration drinks (light alcoholic drinks)

Merara (Bitter) is the only low alcoholic drink which is produced in SALF. In the factory all these three grouped alcohols are produced in the required quality. After they finished their production process and take the required quality, the final liquor will be filled within washed bottles, then capped and labeled and then will be ready to be delivered to the customers.

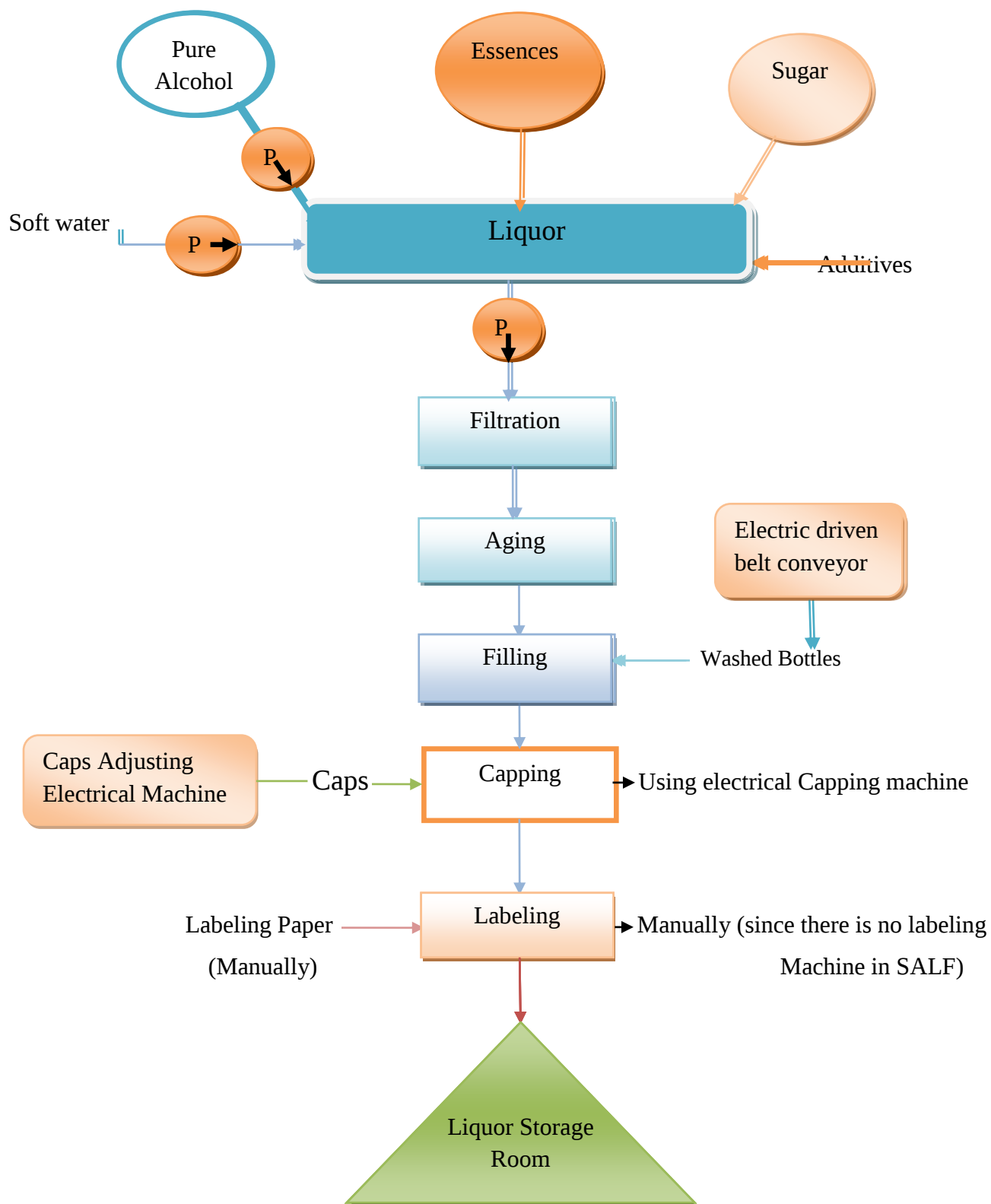


Fig.3.3 Liquor Preparation process flow chart

CHAPTER FOUR

4. ENERGY BILL ANALYSIS OF SALF

4.1 Introduction

Thermal and electrical energies are used for the production of ethanol in SALF and so, the factory pays cost for both energy sources. The energy bills show that as the factory paid 5,163,802.82 Birr and 130,889.70 Birr for furnace oil and electricity respectively for the selected audit year (from July 2002 E.C to June 2003 E.C). The bill analysis is necessarily dependant on the paid money to the used energies by the factory.

4.2 Energy Consumption Data

Bills and all energy consumption data of the factory are listed within the factory logbook for many years. From these only 12-months (from July 1st 2002 E.C to June 30th 2003 E.C) data regarding the factory consumption of furnace oil, electricity, and produced ethyl alcohol are presented in appendix and used in the analysis [Appendix A].

4.3 Energy Consumption of Benchmark Countries

The energy intensities of benchmark factories which produce alcohol at greater amount and had so far good practices of alcohol production at efficient use of energy are included. By taking the average values of fuel oil and electricity energy intensity consumption patterns at national level, the following figures provide the five years (1996–2000) G.C data of benchmark countries [*Australia, Brazil, India, and USA*].

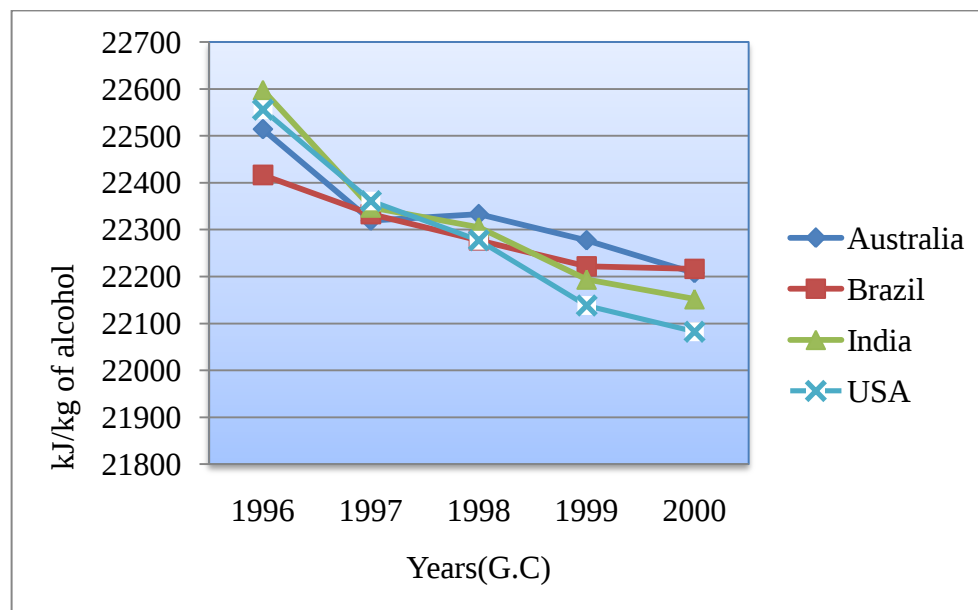


Figure 4.1: Fuel oil energy intensity of the benchmark countries
(Australia, Brazil, India, and USA) [8]

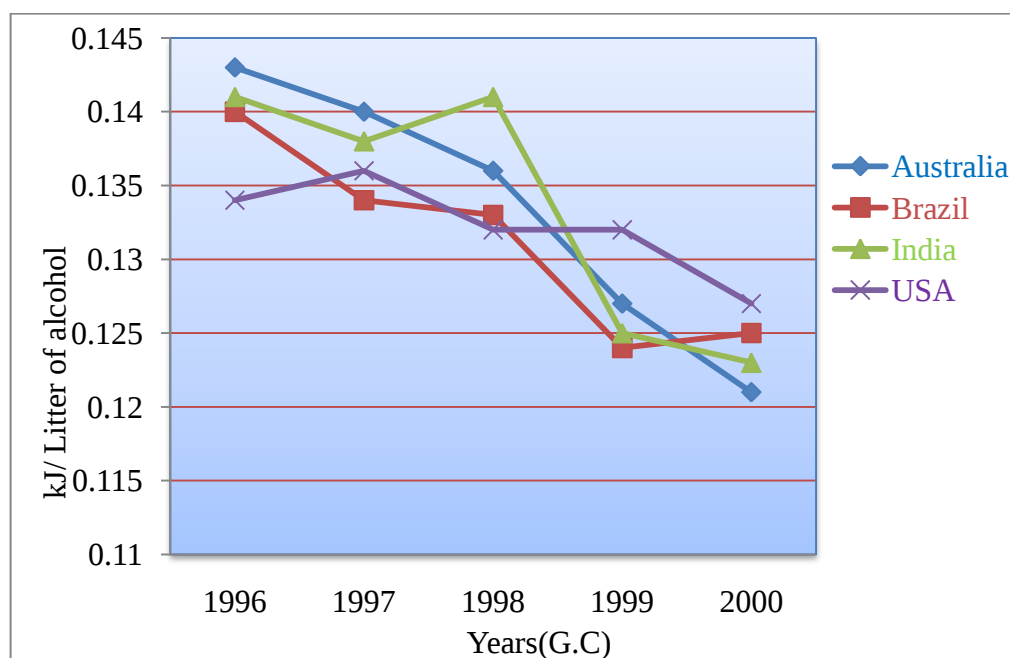


Figure 4.2: Electricity intensity of the benchmark countries
(Australia, Brazil, India, and USA) [8]

4.4 Monthly Energy Cost Analysis of SALF

The collected furnace oil and electricity consumption pattern are processed into monthly factory paid fuel energy intensity. The total cost of fuel oil is the number of liter consumed times the price per liter of fuel. Furnace oil has specific gravity of 0.991 ($\rho_{fuel} = 991 \frac{\text{kg}}{\text{m}^3}$) [14] [20] and the gross calorific value (GCV) of 43,962 kJ/kg. The average price fuel oil in the audit year is 10.41 Birr/liter. Based on the voltage consumption and number of phases (SALF use three phases and high voltage line) used in the factory, cost of electricity varies from month to month. The data collected shows that as the factory consumes the high voltage tariff with flat multiplying factor the consumed kWhs with 0.4993 Birr/kWh [31]. Monthly furnace oil and electricity costs are given by equation 4.1 and 4.2 respectively.

$$\text{MFC} = C_f * \text{Monthly fuel used in liter} \dots\dots\dots (4.1)$$

Where:

MFC – Monthly fuel cost [Birr]

C_f – Average monthly cost of one liter fuel [Birr/liter]

$$\text{MEC} = C_{ele} \text{ Birr/kWh} * \text{monthly electric used in kWh} \dots\dots\dots (4.2)$$

Where:

MEC – Monthly electric cost [Birr/liter]

C_{ele} – Average monthly cost electricity [Birr/kWh]

We can calculate with these formulas or read directly from the factory logbook and tabulated in table 4.1as follows.

Table 4.1 Monthly fuel and electricity cost at SALF

Billing Period (E.C)	Total production of alcohol [liter]	Cost of Fuel [Birr]	Cost of Electricity [Birr]	Total cost [Birr]
July 2002	132434.77	640547.42	5690.86	646238.28
August 2002	171164.06	233472.80	11467.73	244940.53
September 2003	176031.18	230763.27	3058.13	233821.40
October 2003	179355.27	457656.90	2827.01	460483.91

November 2003	182290.90	445998.41	2827.01	448825.42
December 2003	216418.03	781662.99	2827.01	784490.00
January 2003	59565.76	282506.51	4860.49	287367.00
February 2003	158064.73	298397.65	15629.20	314026.85
March 2003	237045.33	316614.52	7053.88	323668.40
April 2003	193100.00	272327.60	13582.02	285909.62
May 2003	252503.51	630176.92	8004.10	638181.02
June 2003	227829.88	568598.59	14059.27	582657.86
Total	2,185,803.42	5,163,802.85	130,889.70	5,294,692.52

4.5 Monthly Energy Intensity Consumption Pattern of SALF

Monthly energy intensity consumptions of the factory are defined as an average monthly energy needed to produce one liter of ethyl alcohol which are given by the following equations.

$$\text{MFEI} = \frac{\text{GCV} \times \rho_f \times \text{monthly fuel used litre}}{\text{monthly alcohol produced}} \dots\dots\dots (4.3)$$

Where:

MFEI – Monthly fuel energy intensity

GCV – Gross calorific value of fuel in kJ/kg of fuel

ρ_f – Density of fuel kg/Liter

$$\text{MEEI} = \frac{\text{Monthly electricity used (KWh)} \times 3600 \text{ sec}}{\text{monthly alcohol produced}} \dots\dots\dots (4.4)$$

Where:

MEEI – Monthly electric energy intensity

Substituting data from [Appendix A] in equations (4.3) and (4.4) and the value are given in table 4.2.

Table 4.2 Monthly fuel and electricity energy intensities of SALF

Billing Period [E.C]	Fuel Energy intensity of [kJ]/Liter of alcohol]	Energy intensity of Electricity [kJ]/Liter of alcohol]	Total monthly produced alcohol [Liter]
July 2002	28,144.34	0.288	132,434.77
August 2002	26,455.91	0.230	171,164.06
September 2003	25,833.63	0.125	176,031.18
October 2003	26,462.07	0.114	179,355.27
November 2003	26,224.26	0.112	182,290.90
December 2003	27,562.35	0.094	216,418.03
January 2003	25,708.93	0.162	59,565.76
February 2003	27,520.69	0.154	158,064.73
March 2003	25,966.01	0.154	237,045.33
April 2003	25,724.23	0.134	193,100.00
May 2003	27,958.78	0.160	227,829.88
June 2003	26,998.42	0.229	252,503.51

The following figures, figure 4.3 and 4.4 provide monthly fuel and electric energy intensities of SALF.

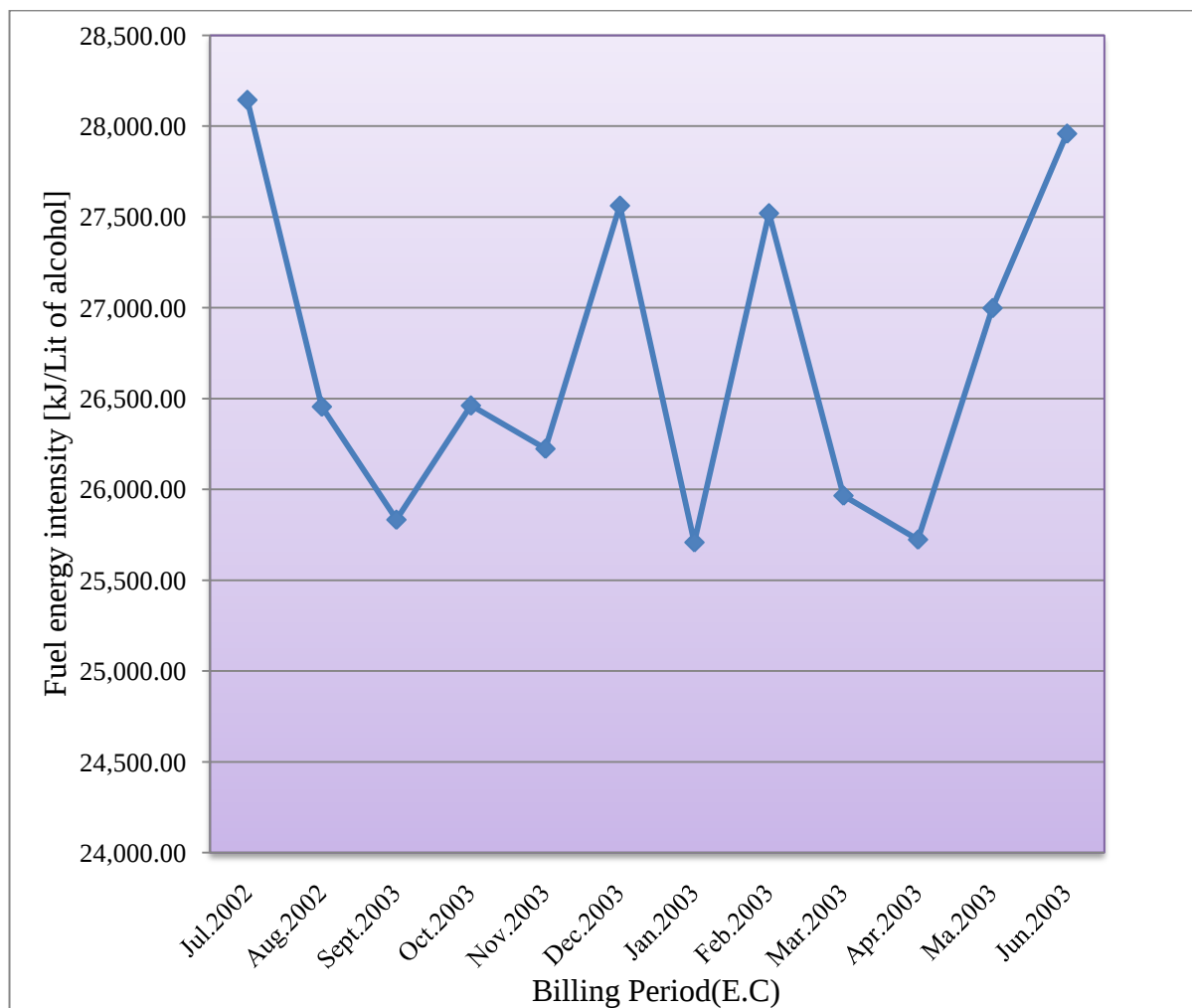


Figure 4.3 Fuel Energy Intensities of SALF

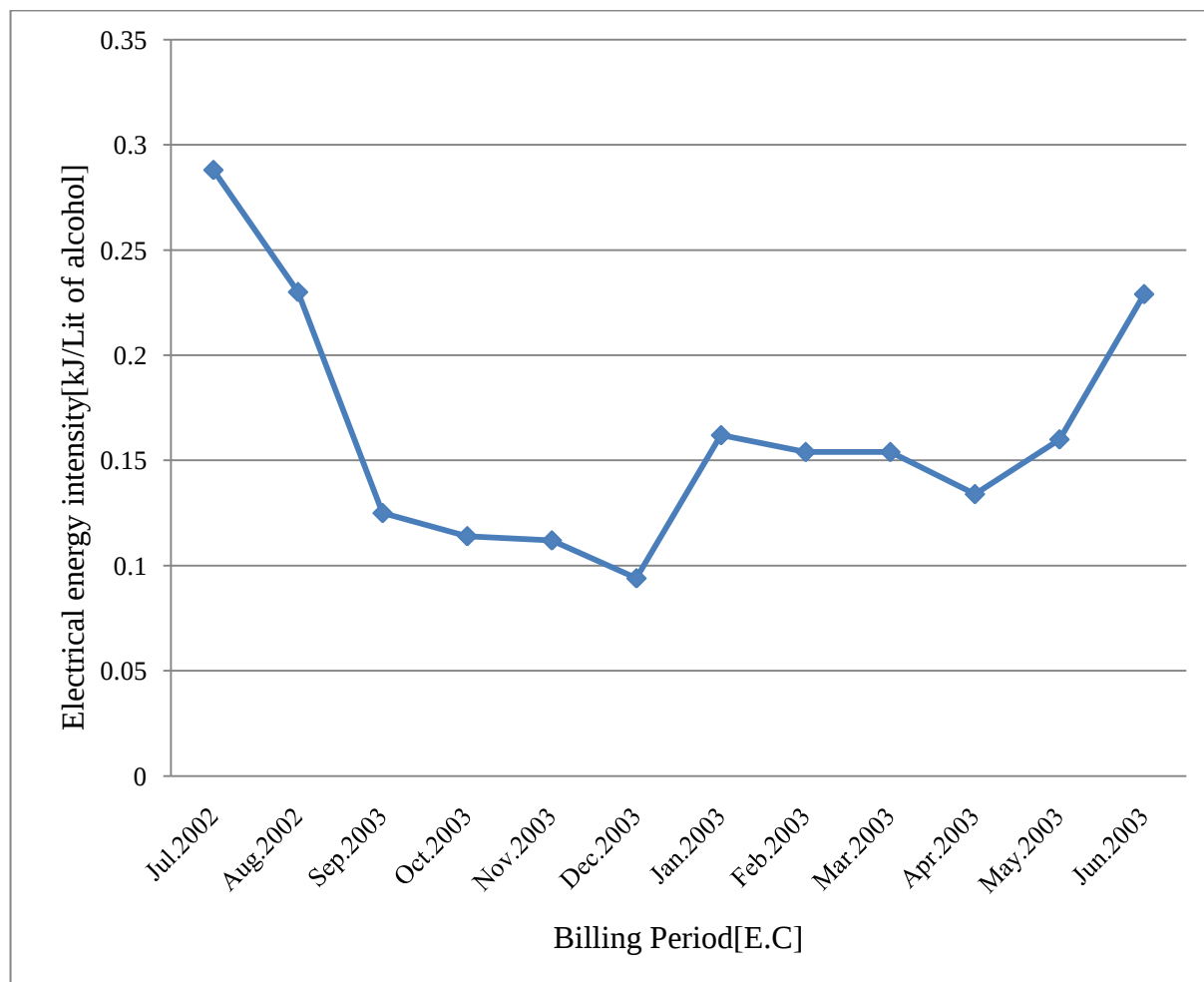


Fig 4.4 Electric Energy intensity of SALF

4.6 Energy Intensity Comparisons of SALF with Benchmarks

The comparison is energy intensities of SALF and the benchmarks. It can be seen that there is a significant difference between the energy intensities of the SALF and the benchmarks. From the twelve months fuel and electric energy intensities analyses of SALF, we can see that the ranges are from 25,708.93 to 28,144.34kJ/Liter of alcohol with monthly average of 26,926.64kJ/Lit alc and 0.094 to 0.288kWh/Lit of alcohol with an average intensity of 0.163kWh/Lit of alcohol respectively. The following table shows the difference in energy intensity of SALF with the benchmarks.

Table 4.3 SALF's energy intensity comparison with benchmarks

Benchmarking countries	Average FEI [$\frac{\text{kJ}}{\text{Lit. of Alcohol}}$]	Average EEI [$\frac{\text{kJ}}{\text{Lit. of Alcohol}}$]	Difference in FEI of SALF and benchmarks [%]	Difference in EEI of SALF and benchmarks [%]
Australia	22,330.32	0.1334	20.58	22.19
Brazil	22,293.00	0.1312	20.79	24.24
India	22,319.24	0.1336	20.64	22.01
USA	22,282.96	0.1322	20.84	23.30

As we see from the table 4.3, the fuel as well the electricity energy intensities of SALF have significant difference from benchmarks. This shows that the energy utilization performance of the factory is low. Due to this, unnecessary cost will occur in SALF. The cost of fuel and electricity occurred due to energy intensity difference can be estimated using the following relation.

$$AC_f = \frac{DEI_f * FAPC * CF}{GCV} \dots\dots\dots (4.5)$$

Where

AC_f – Difference in annual cost due to lower efficiency of fuel energy intensity

DEI_f – Difference of fuel energy intensity

FAPC – Factory annual production capacity

CF – Average cost of fuel in the audit year [Birr]

GCV – Gross calorific value of furnace oil [kJ/Lit]

The following are necessary data used to calculate annual cost occur on the factory due to lower energy intensity efficiency.

- ❖ SALF Production in 2002/2003 E.C = 1,957,974.35 Liters of alcohol
- ❖ Average cost of fuel oil in the audit year = 10.41Birr/liter
- ❖ Average cost of electricity in the audit year = 0.4993 Birr/kWh
- ❖ Specific heat of fuel oil = 43,962 kJ/liter
- ❖ Average value of the difference in fuel energy intensity = 4,620.26 kJ/liter of alcohol.
- ❖ Average value of the difference in electricity energy intensity = 0.0304kWh/ Lit alc

Substituting the above values in equation (4.5) and give the annual energy cost due to lower efficiency of fuel use in the factory as:

$$AC_f = \frac{4620.26 \text{ kJ/Lit}_{alc} * 1,957,974.35 \text{ Lit}_{alc}/\text{Year} * 10.41 \text{ Birr/Lit}_f}{43,962 \text{ kJ/Lit}_f}$$

$$AC_f = 2,142,134.33 \text{ Birr/ year}$$

Annual cost due to improper utilization of electricity in the factory is given by equation (4.6)

$$AC_{ele} = DEI_{ele} * FAPC * EC \dots\dots\dots (4.6)$$

Where:

AC_{ele} – Difference in annual cost due to lower electricity energy intensity

DEI_{ele} – Difference of electricity energy intensity = $0.1074 \frac{\text{kWh}}{\text{Liter}_{alc}}$

$FAPC$ – Factory annual production capacity = $1,957,974.35 \frac{\text{Liter}_{alc}}{\text{year}}$

EC – Cost of electricity = $0.4993 \frac{\text{Birr}}{\text{Kwh}}$

Substituting the above value from the data in equation (4.6) annual energy cost due to lower electricity energy intensity of the factory is given by:

$$AC_{ele} = 0.0304 \frac{\text{kWh}}{\text{Litter}_{alc}} * 1,957,974.35 \frac{\text{Litter}_{alc}}{\text{year}} * 0.4993 \frac{\text{Birr}}{\text{Kwh}}$$

$$AC_{ele} = 29,719.54 \text{ Birr/ year}$$

Therefore, the total annual cost due to low energy utilization performance of the factory is given by the following equation.

$$AEC = AC_f + AC_{ele} \dots\dots\dots (4.7)$$

Substituting the vales of AC_f and AC_{ele} in equation (4.7), and the total annual cost due to lower energy utilization efficiency of the factory will be:

$$AEC = 2,142,134.33 \text{ Birr/ year} + 29,719.54 \text{ Birr/ year}$$

$$AEC = 2,171,853.87 \text{ Birr/ year}$$

4.7 Conclusions on Energy Intensity Comparisons

Based on the above analyses, the factory costs 2,171,853.87 Birr/ year which occur due to poor energy utilization. This cost is in comparison with the benchmarks. Though the benchmarks have their own limitation in energy utilization, it is a relative indication of inefficientness of the factory in energy utilization. So, the factory can conduct energy audit on its major energy producing unit and enduse devices to know the basic energy losses. This helps the factory to find out energy conservation opportunities and take the energy conservation measures.

CHAPTER FIVE

5. PRELIMINARY ENERGY AUDIT OF THE FACTORY

5.1 Introduction

Preliminary energy audit of the factory is performed through inspection of the nine general energy systems. These are:

- Building envelop,
- Boiler and steam distribution systems,
- Heating, ventilating and air conditioning systems (HVAC),
- Electric supply systems,
- Lighting systems,
- Hot water distribution systems,
- Compressed air distribution systems,
- Motors and production process systems using visual inspection,
- Common sense and interview with factory workers in order to identify energy conservation opportunities (ECOs) 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, boiler and steam distribution systems, inspection of the compressed air distribution system, inspection of the motor systems, inspection of the production process, and identification of the major energy systems of the factory systems are selected to be discussed.

5.2 Inspection of Boiler, and Steam and Hot water Distribution Systems

The feed water system provides water to the boiler and regulates it automatically to produce the specified capacity of steam in the boiler. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the different points of end use. Steam pressure is regulated using manual valves from the main distributor and checked with steam pressure gauges at the end use systems. During these times the amount of steam delivered to end use systems may or may not be sufficient enough in comparison with their design as well production capacity.

The fuel system provides furnace oil to boiler and the required heat will be generated as steam. The amount of fuel required to boiler is adjusted manually by boiler operators with a gauge mounted on boiler. ECOs to boiler and steam distribution system are identified using visual inspection, interview with factory workers, and from common knowledge. Energy efficiency opportunities in boiler and steam distribution line systems can be related to feed water quality, combustion, heat transfer, and different boiler losses including blowdown loss. During the preliminary energy audit of boiler and steam distribution system, the following ECOs are discovered. These include:

- Boiler stack temperature exceeds the boiler water temperature by $197.6^{\circ}\text{F} = 92^{\circ}\text{C}$ [Measurement] which is by more than $150^{\circ}\text{F} = 65.56^{\circ}\text{C}$ (it is recommended not to exceed from this value) [27] which lead the boiler to operate inefficiently.
- Periodic soot blowing of boiler, surface cleaning of boiler, and scale removing of the boiler water side are not done properly [Interview].
- Boiler surface, steam delivery pipes to enduse systems, hot water tank, and hot water distribution pipes are not insulated [Inspection].
- The boiler is without an economizer.
- The water treatment plant is not functional which leads the entrance of raw water (water with chemical and gaseous impurities) which results scale formation in the boiler.
- Proper functioning of steam traps are not checked periodically.
- Boiler and distillery column surfaces are not insulated.
- Almost all steam distribution pipe lines are not insulated which lead high energy loss with radiation and convection.

ECOs listed above for boiler plant includes opportunities which can be implemented simply with the routine maintenance program of the factory with no or low cost (periodic soot blowing, Boiler surface cleaning, scale removing of the Boiler water side, checking the proper functioning of steam traps periodically) and others which need further data collection to conduct detail energy audit.

5.3 Inspection of the Distillery Columns

The factory intensively utilized both thermal and electric energy. Large quantity of the thermal energy generated with steam generator is consumed with the production process of potable and Esat alcohols. In comparison with steam consumed for the distillation process, little amount of steam is used for feed water preheating, heating of bottle washing water and dilution of molasses when it becomes solid. The electric energy mainly drives pump and fan motors, used to preheat fuel, used for lighting, and used for different electronic devices.

Distillation is one of the most energy intensive operations in the factory. It is used throughout alcohol producing processes to separate alcohol from water and other solution. The incoming flow is heated, after which the products are separated on the basis of boiling points. The steam provides the heat needed for the evaporation of alcohol with different amount for different distillation steps in different columns.

Inspection of the production process means examination of the processes that consume the total thermal energy produced by the steam generator. From these processes the main one is distillation process takes place in the distillery columns. Hence inspecting the distillery columns of the factory takes the major place of energy evaluation steam energy.

Based on this fact, inspection of distillery columns is conducted using visual inspection, common knowledge, and interview made with factory personnel. The distillation system of the factory was assessed for potential ECOs and the following were obtained.

- Periodic cleaning of the distillation column is not done. The inside portion will develop scale and results large steam consumption and production interruption, and the dirtiness of outer surface also build up a layer which increases heat consumption of distilleries.
- The pressure sensing gauges of the distillery columns are not functional. These problems enforce the operators to feed steam pressure by estimation and leads to consume un-recommended amount of steam pressure (may be below or above the necessary amount of steam pressure will be supplied).
- The trays and cups of the columns are so much old and worn-out.
- Large amount of steam is escape out just after entering to distillery columns due to the openness of the upper part of the columns.

- Shortness in length of columns will slow down the distillation process. When the length of the column is short, the contact time of wine and steam will be also short. As the contact time is short, the distillation process needs more time and the reverse is also true.
- Large quantity of effluent at a temperature of 87.38°C is channeled to the river.

From the above listed ECOs, some of them are low cost or no cost energy conservation opportunities which can be handled with regular maintenance and job of the factory employees and the others require further data collection on vent steam, effluent and fermented wine to conduct an appropriate detail energy audit. These will be discussed in chapter seven of this paper.

5.4 Inspection of Motors

There are more than 15 three phase motors within the power range of 3.3 kW to 18.5 kW in the factory which are used to move pumps, fans and air compressor. The operating time ranges from 365 hr to 6734.25 hr per a year. Inspection of the motors system is conducted using visual inspection, common knowledge on motors and interview made with electrical maintenance personnel. During these times, the inspection shows that as the energy efficiency opportunities in motor systems can be related to efficiency and power factor and the following lists of ECOs are discovered.

- Most of the electric motors are exposed to dirt. This leads them to require high starting power (the motor requires high heating up power for its own parts), rotating parts of motors would retard or might not be functional.
- Lubrication is not done often enough to keep all rotating parts covered with lubricant which lead bearing parts to rub together and cause to wear out and also high heat due to friction (which may lead the motor burnout).
- Some motors are working beyond the required time due to lack of care of the operators, different installed position of motors (driving units) and their driven units (pumps, fans, compressors).
- Most of the motors are old (installed when the factory built), even motors which their nameplate rubout are in use.
- The nameplate power factors are in the ranges of 80% to 88%
- Nameplate efficiencies of the motors are in the ranges of 84.8% to 89.6% (most of the factory motors are under loaded)

Some of the ECOs listed above are simply implemented with the routine maintenance program of the factory with no cost or with low cost and others are those which need further data collection to conduct detail energy audit on motors.

5.5 Detecting the Major Energy utility Systems of the Factory

As it is noticeably discussed in the preceding sections and chapters, there are so many equipments that are engaged in the production of alcohol having direct relation with energy generation or consumption in the factory.

From production process, preliminary energy audit results, and interview made with factory workers, the major energy systems of the factory are found to be:

- Boiler and steam distribution systems,
- Distillery columns, and
- Motors and pumps.

Moreover, of the total energy production from furnace oil, large amount goes to distilleries. Saving energy in alcohol factory would then become a question of improving combustion efficiency of the boiler and a better use of energy that is exhausted through existing distillery columns and also 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 can be conducted through assessment of their energy performance according to the following categories in a separate chapter.

- Detail thermal energy audit of boiler and distilleries.
- Detail electric energy audit of motors and pumps.

CHAPTER SIX

6. DETAIL ENERGY AUDIT OF THE FACTORY BOILER

6.1 Introduction

The thermal energy used to produce alcohol in SALF is obtained from steam-generator (boiler). The main function of boiler is to supply superheated steam to the end use devices. 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. The boiler used by the factory has the following specifications:-

Table 6-1: Boiler specifications

	Specification	Data collection method
Type	Fire tube	Catalogue
Model	S202	Catalogue
Manufactured year [G. C]	1980	Catalogue
Designed capacity $\left[\frac{\text{kg}}{\text{h}} \right]$ @ 15 bar	2000	Catalogue
Working pressure (max/min) [bar]	11/8	Gauge
Diameter [m]	1.88	Catalogue
Length [m]	3.53	Catalogue
Area[m ²]	26.4	Calculated

To know whether the boiler is working with good efficiency or not by performing energy audit and balances, the following data and measurements are required and not limited too.

- Boiler dimensions and surface temperatures,
- Boiler steam pressure, temperature and flow rate,

- Flue gas analysis (flue temperature, constituents of combustion products, flue excess air, and losses)
- Feed water flow rate and temperature,
- Ambient temperature,
- Combustion air flow rate and temperature,
- Fuel oil flow rate and pre-heating temperature, and
- Temperature and flow rate of the boiler blowdown

6.2 Boiler Data Collection

The different data related to steam generation and utilization of the boiler were collected by interview with factory workers, referring to different factory recording books and log sheets, direct recording from factory boiler, and direct measurement using portable instruments.

6.2.1 Flue Gas Analysis

Portable Combustion Analyzer (PCA) is used to collect data on the flue gas emitted from boiler through the chimney. PCA has the capability of measuring, displaying, and storing combustion tests. It will also display flue gas oxygen content, carbon dioxide content, carbon monoxide content, air temperature, flue gas temperature, stack loss, and the current fuel selected. The stored data can then either be viewed on the PCA's display screen, printed using an optional printer, or down-loaded to a computer.

Table 6-2 Measured flue gas data

No.	Flue gas data	Readings
1	Flue gas temperature [°C]	172
2	Ambient temperature [°C]	27
3	Net temperature [°C]	145
4	Flue gas O ₂ content [%]	11
5	Flue gas CO content [ppm]	338
6	Flue gas CO ₂ content [%]	13.1
7	Combustion efficiency [%]	79.7

8	Flue gas excess air [%]		16.2
9	Losses [%]		17.3
	1	Dry flue gas	12.8
	2	Wet flue gas	4.37
	3	CO	0.1
Nitrogen 79%			

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 are measured at different locations. The boiler is cylindrical in shape and surfaces that are exposed to the ambient are front surface, cylindrical surface, and back surface. In addition to boiler surface temperatures blowdown and feed water temperatures are measured.

Table 6.3 Measured boiler data

No.	Measured side of boiler	Surface temperatures [°C]	Ambient temperatures [°C]
1	Front Surface area	109.1	34.7
2	Cylindrical Surface area	45.8	31.3
3	Back surface area	111.5	37.05
4	Blowdown Temperature = 106.8 °C		
5	Feed Water Temperature = 80 °C		
6	Pre-heated Fuel Temperature = 80°C		
7	Datum (ambient) Temperature =27 °C		
8	Steam produced at a temperature of 175 °C & pressure of 9 bars		

6.2.3 Boiler Dimensions Analysis

As it is mentioned above, the boiler is cylindrical in shape and has three surfaces exposed to the ambient air. The surface areas of boiler exposed to the ambient air can be calculated as follows:

$$A_{cs} = \pi DL \dots\dots\dots (6.1)$$

$$A_{cs} = \pi * 1.88m * 3.53m$$

$$A_{cs} = 20.849 \text{ m}^2$$

$$A_{fs} = A_{bs} = \frac{\pi D^2}{4} \dots\dots\dots (6.2)$$

$$A_{fs} = A_{bs} = \frac{\pi*(1.88 \text{ m})^2}{4}$$

$$A_{fs} = A_{bs} = 2.776 \text{ m}^2$$

$$A_t = A_{cs} + A_{fs} + A_{bs} \dots\dots\dots (6.3)$$

$$A_t = (20.84 + 2.776 + 2.776) \text{ m}^2$$

$$A_t = 26.401 \text{ m}^2$$

Caliper was used to measure the internal diameters of feed water flow pipe, fuel oil flow pipe, and blowdown tube. The diameters of each pipe are 0.03175m, 0.0254m, and 0.03175m respectively.

6.2.4 Boiler Fluids Flow Velocity Estimation

Flow meter is used for estimation of fluid flow through pipes. Using this meter, feed water flow velocity, fuel oil flow velocity, and blowdown flow velocity are measured.

Table 6-4 Flow velocities

Item (material to be flow)	Flow type	Diameter of pipes [m]	Average measured Velocities [m/s]
Feed water	Continuous	0.03175	0.97
Fuel oil	Continuous	0.0254	0.0817
Blowdown	Intermittent	0.03175	0.1648
Vent steam	Continuous	Impossible to measure	Impossible to measure

6.3 Mass and Energy Balance

In order to perform the input-output energy and mass balance analysis, the following data are necessary:

- Heating value of furnace oil,
- Mass flow rate of feed water,
- Mass flow rate of fuel, and
- Mass flow rate of blowdown.

6.3.1 Heating Value of Furnace Oil

The calorific value of furnace oil used in the factory is important to determine the energy input to the boiler. The gross calorific value of furnace oil (GCV) is dependent on the physical composition, whereas the net calorific value (NCV) of furnace oil depends on the physical as well as chemical composition. The chemical and physical composition and GCV of furnace oil are shown in table 6.5 [14].

Table 6-5 Composition of furnace fuel oil and ultimate analysis [13]

Composition of furnace oil	Symbol	Ultimate analysis in %
Carbon	C	84
Hydrogen	H ₂	12
Oxygen	O ₂	1.5
Sulfur	S	1.5
Nitrogen	N ₂	0.5
Moisture	M	0.5
Gross calorific value = 43,962 kJ/kg (HHV value of light fuel)		

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 (6.4), the NCV value of furnace oil can be estimated.

$$\text{NCV} = \text{GCV} - (M_{\text{H}_2\text{O}}) * h_{\text{fg}} \dots\dots\dots (6.4)$$

Where:

NCV–Net calorific value

GCV–Gross calorific value

$$\text{GCV} = 43962 \text{ kJ/kg}$$

$M_{\text{H}_2\text{O}}$ = Mass of water vapor in flue gas

$$M_{\text{H}_2\text{O}} = 9 H (1 - \%M) + \%M [14] \dots\dots\dots (6.5)$$

H– Percent mass of hydrogen in the furnace oil

M–Ultimate moisture content in furnace oil

$$h_{\text{fg}} = \text{Enthalpy of vaporization of water} = 2430.353 \text{ kJ/kg}$$

From table 6.5, hydrogen and moisture in furnace oil are 12% and 0.5% respectively. Hence:

$$M_{\text{H}_2\text{O}} = 9 * 0.12 (1 - 0.5) + 0.5 = 1.04 \text{ kg of water vapor/ kg of flue gas}$$

Substituting the values of $M_{\text{H}_2\text{O}}$, GCV and h_{fg} in equation(6.4) and:

$$\text{NCV} = \text{GCV} - (M_{\text{H}_2\text{O}}) * h_{\text{fg}}$$

$$\text{NCV} = 43962 \text{ kJ/kg} - 1.04 * 2430.353 \text{ kJ/kg} = 41434.433 \text{ kJ/kg}$$

6.3.2 Actual Combustion Analysis

Furnace oil combustion analysis can be performed to find the amount of energy liberated during furnace oil combustion. Mass and energy analysis of furnace oil, combustion air, and combustion products are very important.

6.3.2.1 Analysis of the Constituents of Combustion Air

The ambient air used for combustion is composed of Oxygen (21%) and Nitrogen (79%) on dry basis. The air used for combustion is composed of moisture, oxygen and nitrogen at standard condition 25°C and $P_a = 1\text{atm}$ with relative humidity $\phi = 53.25\%$. Absolute humidity and mass fraction of air constituents relative to oxygen must be found to perform the molar analysis of the combustion air constituent.

a) Absolute Humidity Factor (γ_A)

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.

The humidity factor of the air is given by [37]:

$$\text{Absolute Humidity factor } (\gamma_A) = 0.622 \frac{P_v}{P_o} \dots\dots\dots (6.6)$$

Where:

$$P_o = P_a - P_v$$

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

But the value of the partial pressure of the water,

$$P_v = \phi P_{\text{sat}@27^\circ\text{C}},$$

$$\phi = 53.25\%$$

$$P_{\text{sat}@27^\circ\text{C}} = 4.502 \text{ kPa}$$

Hence:

$$P_v = 0.5325 \times 4.502 \text{ kPa} = 2.397 \text{ kPa and}$$

$$P_o = (101.325 - 2.3973) \text{ kPa} = 98.928 \text{ kPa}$$

Therefore, humidity factor:

$$\gamma_A = 0.622 \frac{P_v}{P_o} = 0.622 \times \frac{2.397 \text{ kPa}}{98.928 \text{ kPa}} = 0.024233 \frac{\text{Kg of H}_2\text{O}}{\text{Kg of dry air}}$$

b) Mass Fraction of Air Constituents Relative to Oxygen

In order to perform the actual chemical balance easily 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 constituents relative to oxygen and this is done in table 6.6.

Table 6-6 Mass analysis of dry and wet air constituents

Substance	y = dry air	x = wet air	Molecular mass (M)	Mass of dry air $y * M$	Mass of wet air $x * M$	Mass fraction of wet air $x * M / 28.678$	Mole of substance in air per mole of oxygen
O ₂	0.21	0.2074	32.00	6.72	6.636	0.231	1
N ₂	0.79	0.7804	28.00	22.12	21.85	0.76	3.763
H ₂ O	-	0.01211	18.00	0.00	0.218	0.00899	0.0693
Sum	1.00	1.00	28.84	28.704			

6.3.2.2 Air Fuel Ratio

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

a) Theoretical Air -Fuel Ratio (TAFR)

To determine the theoretical air-fuel ratio of burning furnace oil, a standard 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. The percentage of fuel constituents is presented in table 6-5.

$$\text{TAFR} = [(11.6 \times C) + \{34.8 \times (H_2 - O_2/8)\} + (4.35 \times S)] / 100 \text{ kg /kg of fuel oil} \dots\dots\dots (6.7)$$

$$\text{TAFR} = [(11.6 \times 84) + \{34.8 \times (11.8)\} + (4.35 \times 1.5)] / 100 \text{ kg/kg of fuel oil}$$

$$\text{TAFR} = 13.92 \text{ kg of air/kg of oil [35]}$$

b) Actual Air -Fuel Ratio of Furnace oil (AAFR)

The actual mass of air used during burning of 1 kg of fuel can be easily found using equation (6.8).

$$\text{Actual mass of supplied air (AA)} = \left[1 + \frac{\text{EA}}{100} \right] * \text{TAFR} \dots\dots\dots (6.8)$$

Where: EA - excess air supplied

TAFR - theoretical amount of air fuel ratio

But the excess air supplied can be obtained by using the following equation.

$$\text{Excess air supplied (EA)} = \frac{O_2\%}{21\% - O_2\%} * 100 \quad [35] \dots\dots\dots (6.9)$$

But % O_2 measured in flue gas = 11 % and substituting in equation (6.8), the excess air will be:

$$EA = \frac{O_2\%}{21\% - O_2\%} * 100 = \frac{11\%}{21\% - 11\%} * 100 = 110 \% \text{ and then:}$$

$$AAFR = \left[1 + \frac{EA}{100} \right] * TA = \left[1 + \frac{110}{100} \right] * 13.92 = 29.23 \text{ kg of air / kg of fuel}$$

From this result we can see that the TAFR and AAFR have significant differences (TAFR is 13.92 kg of air/kg of oil and AAFR is 29.23kg of air / kg of fuel). The AAFR deviates with a magnitude of 15.31 kg of air/kg of oil from the recommended value and shows too much excess inlet air is supplied.

6.3.2.3 Mass Flow Rate Analysis of Dry Flue Gases

In order to calculate the energy losses due to flue gases (stack loss), the mass flow rate of the flue gases must be found. Based on the compositions of the gas products of the actual chemical reactions, the mass flow rate of the dry flue gases can be determined.

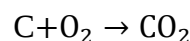
Table 6-7 Molecular weights of fuel constituents

Element or Compound	C	O_2	H_2	S	N_2	C_2O	S_2O	H_2O
Molecular Weight	12	32	2	32	28	44	64	18

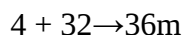
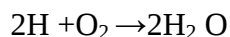
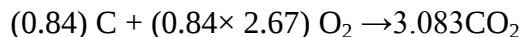
The combustible elements in furnace oil are carbon, hydrogen and sulfur. During burning of furnace oil with dry air, these elements give carbon dioxide, water and sulfur dioxide with inert Nitrogen in the product. This reaction is given by equation (6.10):



Mathematically (for each constituent elements of fuel):

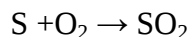
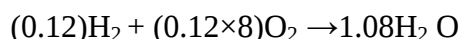


12 kg of C requires 32 kg of O_2 to form 44 kg of CO_2 . Therefore 1 kg of C requires $\frac{32}{12}$ kg of O_2 . i.e. 2.67 kg of O_2 .



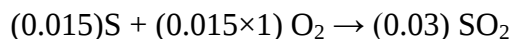
4 kg of H_2 requires 32 kg of O_2 to form 36 kg of H_2O , therefore 1 kg of H_2 requires $\frac{32}{4}$ kg.

i.e. 8 kg of O_2



32 kg of S requires 32 kg of O_2 to form 64 kg of SO_2 , therefore 1 kg of S requires $\frac{32}{32}$ kg.

i.e. 1 kg of oxygen.



Excess air = Actual air supplied – Theoretical air required

EA = 29.23 kg – 13.92 kg = 15.31 kg of air. This value is too much in comparison with the recommended value (i.e. 15%)

Excess O_2 = 15.31 kg $\times$ 0.23 (by mass) = 3.52 kg

Excess N_2 = 15.31 kg $\times$ 0.77 (by mass) = 11.79 kg

The final constituents of flue gas with 15.31 kg (102.1%) of excess air for every 1 kg fuel is the summation of;

$$\left. \begin{array}{l} \text{CO}_2 = 3.083 \text{ kg /kg of fuel} \\ \text{H}_2\text{O} = 1.08 \text{ kg /kg of fuel} \\ \text{SO}_2 = 0.03 \text{ kg /kg of fuel} \\ \text{N}_2 = (11.79 + 10.245) \text{ kg /kg of fuel} \\ \text{N}_2 = 22.034 \text{ kg /kg of fuel} \end{array} \right\} \dots\dots\dots (6.11)$$

Therefore, total mass of flue gas (m) = 58.46 kg flue/ kg fuel

Multiplying total mass of flue gas (m) = 29.747 kg flue/ kg fuel with mass flow rate of furnace oil gives the mass flow rate of flue gases.

$$\dot{m}_{\text{fl}} = 29.747 \frac{\text{kg}_{\text{flue}}}{\text{kg}_{\text{fuel}}} * 0.0413 \frac{\text{kg}_{\text{fuel}}}{\text{sec}} \dots\dots\dots (6.12)$$

$$\dot{m}_{\text{fl}} = 1.23 \frac{\text{kg}_{\text{flue}}}{\text{sec}}$$

6.3.3 Furnace Combustion Temperature Estimation

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. But, the combustion temperature prevailing in the furnace could be readily estimated from the moisture content and excess air used during combustion [16]. For 0.5% moisture content of furnace oil, the furnace temperature at 102.1% excess air is 605.9°C .

6.3.4 Specific Heat of Dry Flue Gases

For furnace oil, the specific heat of dry flue gas is given by:

$$C_{P_{fg}} = (0.3 + 0.000038 T_{fur}) \text{ kcal/kg}^\circ\text{C} \quad [16] \dots\dots\dots (6.13)$$

Where:

T_{fur} –Furnace temperature

Substituting the value of furnace temperature (605.9°C) and the specific heat of the flue gas is given by:

$$C_{P_{fg}} = (0.3 + 0.000038 * 605.9) \text{ kcal/kg}^\circ\text{C}$$

$$C_{P_{fg}} = 0.323 \text{ kcal/kg}^\circ\text{C} = 1.343 \text{ kJ/kg}^\circ\text{C}$$

6.3.5 Mass Balance Check

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

6.3.5.1 Determination of Mass Flow Rate of Furnace Oil

Since the factory uses furnace oil as fuel source to generate steam, determining the mass flow rate of furnace oil is important to know the boiler input energy. The mass flow rate can be determined by directly multiplying the fuel flow velocity, area of the fuel flow pipe and the density of fuel. The measured velocity, pipe diameter and density are presented in table 6.3.

The mass flow rate of furnace oil and pipe flow area can be obtained using equation (6.14) and (6.15) respectively.

$$\dot{m}_f = A_f * V_f * \rho_f \dots\dots\dots (6.14)$$

Where:

A_f – Area of fuel flow pipe

$$A_f = \frac{\pi D^2}{4} \dots\dots\dots (6.15)$$

D – Diameter of fuel flow pipe = 1inch = 2.54 cm = 0.0254m

$$A_f = \frac{\pi(0.0254\text{m})^2}{4}$$

$$A_f = 0.00051\text{m}^2$$

V_f – Velocity of fuel flow = 0.0817 m/s

ρ_f – Density of fuel oil = 991 kg/m³ [7]

Substituting pipe area and the above data in equation (6.14), the mass flow rate of furnace oil is:

$$\dot{m}_f = A_f * V_f * \rho_f$$

$$\dot{m}_f = 0.00051\text{m}^2 * 0.0817 \text{ m/s} * 991 \text{ kg/m}^3$$

t_d = daily operating hours = 18.45 [Interview and Inspection]

$$\dot{m}_f = 0.0413 \text{ kg/s} * 66,420 \text{ s/day} = 2743.15 \frac{\text{Kg}}{\text{day}}$$

6.3.5.2 Determination of Mass Flow Rate of Feed Water

The mass flow rate of feed water can be calculated by multiplying feed water flow velocity with feed water flow pipe area and density of feed water. The measured velocity, pipe diameter and density are presented in Table 6.4. The mass flow rate of feed water and pipe flow area can be obtained using equation (6.15) and (6.16) respectively.

$$\dot{m}_w = A_w * V_w * \rho_w \dots\dots\dots (6.15)$$

A_w – Area of feed water flow pipe

$$A_w = \frac{\pi D^2}{4} \dots\dots\dots (6.16)$$

D – Diameter of feed water flow pipe = 1 1/4 inch = 3.175 cm = 0.03175m

$$A_w = \frac{\pi(0.03175\text{m})^2}{4} = 0.00079\text{m}^2$$

V_w – Velocity of feed water flow = 0.97 m/s

$$\rho_w - \text{Density of water} = 1000 \text{ kg/m}^3$$

Substituting the value of the above data in equation (6.15) and the daily mass flow rate of feed water becomes:

$$\dot{m}_w = 0.00079 \text{ m}^2 * 0.97 \text{ m/s} * 1000 \text{ kg/m}^3 = 0.7663 \text{ kg/s}$$

t_d – Daily total effective boiler working time

$$t_d = 18.45 \text{ hrs} = 66420 \text{ sec [Interview and Inspection]}$$

$$\dot{m}_w = 0.7663 \frac{\text{kg}}{\text{s}} * 66420 \frac{\text{sec}}{\text{day}} = 50897.646 \frac{\text{kg}}{\text{day}}$$

6.3.5.3 Determination of Mass Flow Rate of Blowdown

Boiler blowdown is one of the major causes of energy loss from boiler drum. In the factory, blowdown is done manually by operating a valve fitted to a discharge pipe at the bottom of the boiler shell. Blowdown is done to reduce total dissolved solids (TDS) present in the boiler as a residue. It is done by opening a 0.03175m diameter pipe within 2 hours gap for 5 minutes (11 times within a day for each 5 minutes) [Interview and Inspection]. The mass flow rate of blowdown and pipe flow area can be obtained using equation (6.17) and (6.18) respectively.

$$\dot{m}_{bd} = V_{bd} * A_{bd} * \rho_{bd} \dots\dots\dots (6.17)$$

Where:

$$V_{bd} - \text{Velocity of blowdown flow} = 0.2047 \text{ m/s}$$

A_{bd} – Blowdown pipe area

$$A_{bd} = \frac{\pi D^2}{4} \dots\dots\dots (6.18)$$

$$D - \text{Diameter of blowdown pipe} = 0.03175 \text{ m}$$

$$A_{bd} = \frac{\pi * (0.03175)^2}{4} = 0.00079 \text{ m}^2$$

$$\rho_{bd} - \text{Density of blowdown} = 951 \frac{\text{kg}}{\text{m}^3} [38]$$

Substituting the above values in equation (6.17) and the daily mass flow rate of the blowdown will be obtained.

$$\dot{m}_{bd} = V_{bd} * A_{bd} * \rho_{bd}$$

$$\dot{m}_{bd} = 0.2047 \text{ m/s} * 0.00079 \text{ m}^2 * 951 \frac{\text{kg}}{\text{m}^3} = 0.1538 \frac{\text{kg}}{\text{s}}$$

t_d – Daily total time of blowdown

$t_d = 2536.875 \text{ sec}$ [Interview and Inspection]

$$\dot{m}_{bd} = 0.154 \frac{\text{kg}}{\text{s}} * 2536.875 \frac{\text{s}}{\text{day}} = 390.679 \frac{\text{kg}}{\text{day}} = 0.154 \frac{\text{kg}}{\text{s}}$$

6.3.5.4 Mass Flow Rate Analysis of Steam

Estimating the total steam production is important to estimate the energy carried away by the steam. Direct measuring of steam flow velocity is impossible due to the absence of ultra sonic flow meter. Hence the alternative way to estimate the mass flow rate of steam is using water balance of the boiler. The mass balance of steam seems as follows by considering leakages observed are insignificant.

$$\dot{m}_s = \dot{m}_w - \dot{m}_{bd} \dots\dots\dots (6.19)$$

Where:

$\dot{m}_s$ – Mass flow rate of steam (output)

$\dot{m}_w$ – Mass flow rate of feed water (input) = $50897.646 \frac{\text{kg}}{\text{day}}$

$\dot{m}_{bd}$ – Mass flow rate of blowdown (output) = $390.679 \frac{\text{kg}}{\text{day}}$

Substituting the above data in (6.13) and the mass flow rate of steam is given as:

$$\dot{m}_s = (50897.646 - 390.679) \frac{\text{kg}}{\text{day}}$$

$$\dot{m}_s = 50506.967 \frac{\text{kg}}{\text{day}} = 0.76 \frac{\text{kg}}{\text{s}}$$

6.4 Energy Analysis of the Boiler

Thermal energy audit analysis of boiler must be conducted to know thermal and combustion efficiency of boiler. The analysis is done based on the energy inputs and outputs of the boiler. All inputs and outputs of the boiler are shown in figure 6.1

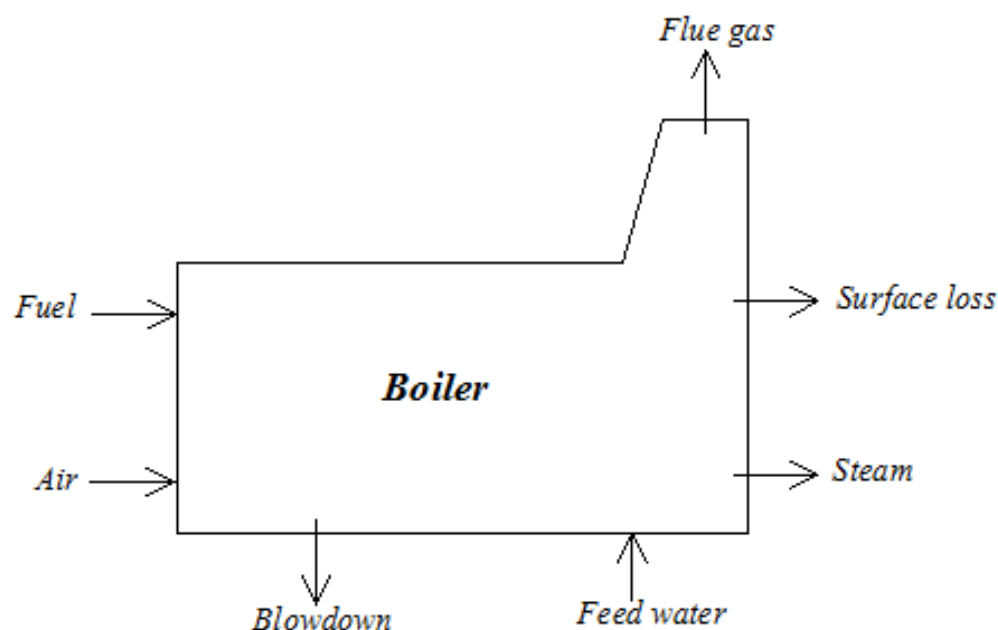


Fig. 6.1 Energy Input output diagram of Boiler

6.4.1 Determination of Input Energies

As illustrated in figure 6.1, heat due to pre-heating of furnace oil, combustion air and feed water are the input energies of the boiler.

6.4.1.1 Furnace Fuel Oil Energy

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

a) Chemical Energy

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.

$$Q_f = \dot{m}_f * \text{GCV} \dots\dots\dots (6.20)$$

Where:

Q_f – Chemical energy of the fuel

$\dot{m}_f$ – Mass flow rate of the fuel = 0.0413 kg/s

GCV – Gross calorific value of the fuel = 43962 kJ/kg

Substituting the above data in equation (6.20), then the chemical energy of the fuel will be:

$$Q_f = \dot{m}_f * \text{GCV} = 0.0413 \text{ kg/s} * 43962 \text{ kJ/kg} = 1815.63 \text{ kW}$$

b) Energy due to 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.

[Furnance oil]_{@ 27 °C} $\longrightarrow$ [Furnance oil]_{@ 80 °C}

The energy due to pre-heating temperature can be obtained using the following equation (6.21)

$$Q_{pf} = \dot{m}_f * C_f(T_f - T_{am}) \dots\dots\dots (6.21)$$

Where:

Q_{pf} – Energy content due to fuel pre-heating

C_f – Specific heat of fuel = $0.879 \text{ kJ/kg } ^\circ\text{K}$

T_{pf} – Fuel pre-heating temperature = 80°C

T_{am} – Ambient temperature = 27°C

Substituting the above data in equation (6.21) the energy content of the fuel due to its pre heating becomes:

$$Q_{pf} = \dot{m}_f * C_f(T_f - T_{am})$$

$$Q_{pf} = 0.0413 \text{ kg/s} * 0.879 \text{ kJ/kg } ^\circ\text{K} (80^\circ\text{C} - 27^\circ\text{C}) = 1.924 \text{ kW}$$

6.4.1.2 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.

$$Q_a = 0$$

6.4.1.3 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.

[Feed water]@ 27 °C $\longrightarrow$ [Feed water]@ 80 °C

The energy due to pre-heating temperature can be obtained using the following equation (6.22)

$$Q_{pw} = \dot{m}_w * C_w(T_w - T_{am}) \dots\dots\dots (6.22)$$

Where:

Q_{pw} – Energy of feed water

$\dot{m}_w$ – Mass flow rate of feed water = $0.7663 \frac{\text{Kg}}{\text{s}}$

C_w – Specific heat of water = $4.18 \frac{\text{kJ}}{\text{kg } ^\circ\text{K}}$ [25]

T_w – Temperature of feed water = 80 °C

T_{am} – Ambient temperature = 27°C substituting the value of the above data in equation (6.22) the heat content in feed water becomes:

$$Q_{pw} = \dot{m}_w * C_w(T_w - T_{am})$$

$$Q_{pw} = 0.7663 \frac{\text{Kg}}{\text{s}} * 4.18 \frac{\text{kJ}}{\text{kg } ^\circ\text{K}} (80 ^\circ\text{C} - 27 ^\circ\text{C}) = 169.77 \text{ kW}$$

6.4.2 Determination of the Output Energies

The output energy associated with the burning of furnace oil in the combustion includes:

- Loss of sensible heat of the dry flue gas,
- Loss due to the present of H_2 in fuel (loss due to latent heat),
- Loss due to the moisture content of air,
- Loss of heat by radiation and convection from boiler surface,

- Loss due to the moisture content of the fuel,
- Boiler blowdown loss, and
- Useful heat to steam.

6.4.2.1 Heat Loss due to Sensible Heat of the Dry Flue Gas [39]

The energy loss due to dry flue gas leaving the furnace 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 executed using equation (6.23).

$$\dot{Q}_{fl} = \dot{m}_{fl} * C_{Pfl}(T_{fl} - T_{am}) \dots\dots\dots (6.23)$$

Where:

$\dot{Q}_{fl}$ – Heat loss due to sensible heat of the dry flue gas

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

C_{Pfl} – Specific heat capacity of flue gas = $1.35 \text{ kJ/kg } ^\circ\text{K}$

T_{fl} – Flue gas temperature = 172°C

T_{am} – Ambient temperature = 27°C

But, $\dot{m}_{fl}$ is determined by multiplying the mass of dry flue gas (m_{fl}) by mass flow rate of the fuel, and also m_{fl} = Mass of dry flue gas = Mass of CO_2 + Mass of H_2O + Mass of SO_2 + Mass of O_2 + Mass of N_2

$$m_{fl} = (3.083 + 1.08 + 0.03 + 3.52 + 22.034) \text{ kg/kg of fuel}$$

$$m_{fl} = 29.747 \text{ kg(dry flue gas) / kg of fuel}$$

Therefore; $\dot{m}_{fl}$ is given by:

$$\dot{m}_{fl} = m_{fl} * \dot{m}_f \dots\dots\dots (6.24)$$

$$\dot{m}_{fl} = 0.0413 \text{ kg/s} * 29.747 \text{ kg of dry flue gas / kg of fuel}$$

$$\dot{m}_{fl} = 2.415 \frac{\text{kg (dry flue gas)}}{\text{s}} = 8694 \text{ kg of dry flue gas/hr}$$

Substitute the above data in equation (6.24) and energy loss due sensible heat of the dry flue gas will be:

$$Q_{fl} = \dot{m}_{fl} * C_{Pfl}(T_{fl} - T_{am})$$

$$Q_{fl} = 1.23 \frac{\text{kg dry flue gas}}{\text{s}} * 1.35 \text{ kJ/kg } ^\circ\text{K} * (172^\circ\text{C} - 27^\circ\text{C})$$

$$Q_{fl} = 240.77 \text{ kW}$$

6.4.2.2 Heat Loss due to the Presence of H_2 in Fuel

During 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 can be estimated using equation (6.25).

$$Q_{H_2} = M_{H_2O} * \dot{m}_f [h_{fw@27^\circ\text{C}} + C_p(T_{fl} - T_{am})] \dots\dots\dots (6.25)$$

Where:

Q_{H_2} – Heat Loss due to the Presence of H_2 in Fuel

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

$\dot{m}_f$ – Mass flow rate of fuel = 0.0413 kg/s

$h_{fw@27^\circ\text{C}}$ – Enthalpy of water = 2430.353 kJ/kg

C_p – Specific heat capacity = $1.88 \text{ kJ/kg } ^\circ\text{K}$ [25]

T_{fl} – Flue gas temperature = 172°C

T_{am} – Ambient temperature = 27°C

Substituting the above data in equation (6.25) the heat loss due to evaporation of water formed due to hydrogen in the fuel is:

$$Q_{H_2} = M_{H_2O} * \dot{m}_f [h_{fw@27^\circ\text{C}} + C_p(T_{fl} - T_{am})]$$

$$Q_{H_2} = 1.08 \frac{\text{kg of water}}{\text{kg of fuel}} * 0.0413 \text{ kg/s} \left[2430.353 \text{ kJ/kg} + 1.88 \text{ kJ/kg } ^\circ\text{K} (172^\circ\text{C} - 27^\circ\text{C}) \right]$$

$$Q_{H_2} = 120.56 \text{ kW}$$

6.4.2.3 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:

$$Q_{ma} = AAS * \gamma_A * \dot{m}_f [C_p(T_{fl} - T_{am})] \dots\dots\dots (6.26)$$

Where:

AAS – Actual air supplied 29.23 kg of air / kg of fuel

$\gamma_A = 0.024233$ kg of H_2O / kg of dry air

$\dot{m}_f$ – Mass flow rate of fuel

Substituting these data in equation (6.26), and gives:

$$Q_{ma} = AAS * \gamma_A * \dot{m}_f [C_p(T_{fl} - T_{am})]$$

$$Q_{ma} = 29.23 \text{ kg of air / kg of fuel} * 0.0122 \text{ kg of } H_2O/\text{kg of dry air} * 0.0413 \text{ kg/s} * [1.88 \text{ kJ/kg}^\circ\text{K} (172^\circ\text{C} - 29^\circ\text{C})]$$

$$Q_{ma} = 4.02 \text{ kW}$$

6.4.2.4 Heat Loss due to Moisture Present in Fuel

During 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:

$$Q_{mf} = M * \dot{m}_f [h_{fw@27^\circ\text{C}} + C_p(T_{fl} - T_{am})] \dots\dots\dots (6.27)$$

Where:

M – Moisture in fuel = 0.5 %

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

$h_{fw@27^\circ\text{C}}$ – Enthalpy of water = 2430.35 kJ/kg

C_p – Specific heat capacity = $1.88 \text{ kJ/kg}^\circ\text{K}$

T_{fl} – Flue gas temperature = 172°C

T_{am} – Ambient temperature = 27°C

Substituting the above data in equation (6.27), the heat loss due to evaporation of water formed due to moisture in the fuel can be calculated:

$$Q_{mf} = M * \dot{m}_f [h_{fw@27^\circ\text{C}} + C_p(T_{fl} - T_{am})]$$

$$Q_{mf} = 0.005 * 0.0413 \text{ kg/s} \left[2430.353 \frac{\text{kJ}}{\text{kg}} + 1.88 \frac{\text{kJ}}{\text{kg}^\circ\text{K}} * (172^\circ\text{C} - 27^\circ\text{C}) \right]$$

$$Q_{mf} = 0.56 \text{ kW}$$

6.4.2.5 Heat Loss by Radiation and Convection from Boiler Surface

As wind crosses over the boiler surface, energy will be lost from the boiler surface to the wind by convection. In addition to this, there is also energy loss through radiation due to difference in temperature between the ambient air and the boiler surface. The energy loss due to convection and radiation is given by [28].

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 \right] + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \sqrt{\frac{196.85V + 68.9}{68.9}} \right\} \frac{W}{m^2} * S_{(i)A} \dots\dots\dots (6.28)$$

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 \right] + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \sqrt{\frac{0 + 68.9}{68.9}} \right\} \frac{W}{m^2} * S_{(i)A}$$

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 \right] + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \right\} \frac{W}{m^2} * S_{(i)A}$$

Where:

$T_{(i)s}$ – Front, cylindrical and back surface temperatures with values of 382.25°k, 318.95°k, and 384.65 °k respectively.

V– Wind velocity = 0 (since the boiler is working in door condition)

$T_{(i)a}$ – Local ambient temperatures for front, cylindrical and back surfaces and have values of 307.85°k, 304.45°k and 310.2°k respectively.

$S_{(i)A}$ - Front, cylindrical and back surface areas with values of 2.776m², 20.849 m² and 2.776 m² respectively.

Substituting the values of the above data in the following equation and the total heat loss due to convection and radiation from boiler surface will be:

Case1:

$$Q_{fs} = \left\{ 0.548 \left[\left(T_{(front)s} / 55.55 \right)^4 - \left(T_{(front)a} / 55.55 \right)^4 \right] + 1.957 (T_{(front)s} - T_{(front)a})^{1.25} \right\} \frac{W}{m^2} * S_{(front)A}$$

$$Q_{fs} = \left\{ 0.548 \left[\left(382.25 / 55.55 \right)^4 - \left(307.85 / 55.55 \right)^4 \right] + 1.957 (382.25 - 307.85)^{1.25} \right\} \frac{W}{m^2} * 2.776m^2 = 3.163kW$$

Case2:

$$Q_{cyls} = \left\{ 0.548 \left[\left(T_{(cyl)s} / 55.55 \right)^4 - \left(T_{(cyl)a} / 55.55 \right)^4 \right] + 1.957 (T_{(cyl)s} - T_{((cyl)a})^{1.25} \right\} \frac{W}{m^2} * S_{(cyl)A}$$

$$Q_{cyls} = \left\{ 0.548 \left[\left(318.95 / 55.55 \right)^4 - \left(304.45 / 55.55 \right)^4 \right] + 1.957 (318.95 - 304.45)^{1.25} \right\} \frac{W}{m^2} * 20.849 m^2 = 3.263 kW$$

Case3:

$$Q_{bs} = \left\{ 0.548 \left[\left(T_{(back)s} / 55.55 \right)^4 - \left(T_{(back)a} / 55.55 \right)^4 \right] + 1.957 (T_{(back)s} - T_{((back)a})^{1.25} \right\} \frac{W}{m^2} * S_{(back)A}$$

$$Q_{bs} = \left\{ 0.548 \left[\left(384.65 / 55.55 \right)^4 - \left(310.2 / 55.55 \right)^4 \right] + 1.957 (384.65 - 310.2)^{1.25} \right\} \frac{W}{m^2} * 2.776 m^2 = 3.206 kW$$

Therefore: the total heat loss from boiler surface due to radiation and convection will be:

$$Q_{ts} = Q_{fs} + Q_{cyls} + Q_{bs}$$

$$Q_{ts} = 3.163 kW + 3.263 kW + 3.206 kW = 9.63 kW$$

6.4.2.6 Boiler Blowdown Loss [38]

The factory practice intermittent blowdown [Inspection] to avoid impurities (chemical and gaseous) which resulted from improper treatment of feed water and condensates.

$$Q_{bd} = \dot{m}_{bd} * h_{bd@106.8^\circ C} \dots\dots\dots (6.29)$$

Where:

$$\dot{m}_{bd} - \text{Mass flow rate of blowdown} = 390.68 \frac{\text{Kg}}{\text{day}} = 0.154 \frac{\text{Kg}}{\text{s}}$$

$$h_{bd@106.8^\circ C} - \text{Enthalpy of blowdown} = 447.82 \text{ kJ/kg}$$

Substituting the above data in equation (6.29) the energy loss due to blowdown is given

$$Q_{bd} = \dot{m}_{bd} * h_{bd@106.8^\circ C}$$

$$Q_{bd} = 390.679 \text{ kg/day} * 447.82 \text{ kJ/kg}$$

$$Q_{bd} = 0.154 \text{ kg/s} * 447.82 \text{ kJ/kg} = 68.96 kW$$

6.4.2.7 Estimation of Heat Carried by the Useful 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 6.2. The output energy can be obtained using equation (6.30) as follows.

$$Q_s = \dot{m}_s * h_{gs} \dots\dots\dots (6.30)$$

Where:

Q_s – Heat carried away by the steam

$\dot{m}_s$ – Mass flow rate of steam=50390.106 kg / day

h_{gs} – Enthalpy of super heated steam at a temperature of 175°C and pressure 9bar

h_{gs} =2110.353 kJ/kg

Substituting the value of the above data in equation (6.30) the heat carried away by the steam will be:

$$Q_s = \dot{m}_s * h_{gs}$$

$$Q_s = 0.7587 \text{ kg / sec} * 2110.353 \text{ kJ/kg} = 1601.13 \text{ kW}$$

Table 6-8 Summery of Boiler input-output energies

No.	Input energy [kW]	No.	Output energy [kW]
1	Fuel due to its heat content = 1815.631	1	Heat loss due to dry flue gas = 240.77
2	Fuel sensible heat = 1.924	2	Heat loss due to hydrogen in furnace fuel oil = 120.56
3	Feed water = 169.77	3	Heat loss due to moisture in air = 4.02
4	Combustion air = 0	4	Heat loss due to moisture in fuel = 0.56
5	$\sum_{i=1}^4$ Energy inputs = 1987.33	5	Surface loss = 9.63
		6	Blowdown loss = 68.96
		7	Heat carried away by the steam = 1601.13
			$\sum_{i=1}^4$ Energy losses = 365.91
			$\sum_{i=1}^6$ Energy losses = 444.50
			$\sum_{i=1}^6$ (losses) + Useful heat) = 2045.63

As we see from the above table, the total input energy to the boiler and output energy from boiler are 2005.43kW and 2046.42kW respectively. The difference between inputs and outputs is 58.3kW (2.85%) which is the result of measuring errors and unaccounted losses.

6.5 Energy Sankey Diagram

The sankey diagram is a very useful tool to represent whole input and output energy flows in any energy enduse device after carrying out energy balance calculations [30]. Based on the calculations summarized in table 6.8, the following sankey diagram is done.

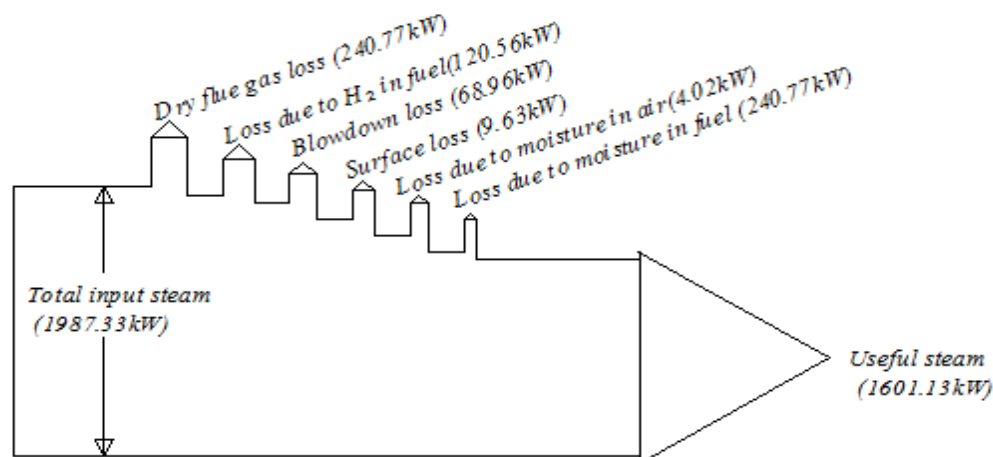


Fig 6.2 Energy Sankey diagram of Boiler

6.6 Efficiency of the Boiler [27]

Overall boiler efficiency is a true indication of the effectiveness of the system. It shows whether the boiler is working with good or poor performance. To determine this, input-output mass balance analysis is necessary.

6.6.1 Energy Efficiency of the Boiler Based on Heat Loss Method

This method is based on all the heat losses of the boiler. All boiler losses will be added and subtracted from 100%, the resulting value is the boiler fuel to steam ratio which is boiler efficiency.

6.6.1.1 Thermal Efficiency

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

$$\eta_{th} = \left[1 - \frac{\sum_{i=1}^6 \text{Energy losses}}{\sum_{i=1}^4 \text{Energy inputs}} \right] * 100\% \dots\dots\dots (6.31)$$

By substituting the values from table 6.8, the thermal efficiency will be:

$$\eta_{th} = \left[1 - \frac{\sum_{i=1}^6 \text{Energy losses}}{\sum_{i=1}^4 \text{Energy inputs}} \right] * 100\% = \left[1 - \frac{444.5}{1987.33} \right] * 100\%$$

$$\eta_{th} = 77.63\%$$

6.6.1.2 Combustion Efficiency

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

$$\eta_{\text{comb}} = \left[1 - \frac{\sum_{i=1}^4 \text{Energy losses}}{\sum_{i=1}^4 \text{Energy inputs}} \right] * 100\% \dots\dots\dots (6.32)$$

Substituting the values of the summations of energy losses and energy inputs from table 6.8 and the thermal efficiency will be

$$\eta_{\text{comb}} = \left[1 - \frac{\sum_{i=1}^4 \text{Energy losses}}{\sum_{i=1}^4 \text{Energy inputs}} \right] * 100\% = \left[1 - \frac{365.91}{1987.33} \right] * 100\%$$

$\eta_{\text{comb}} = 81.59\%$ (This value is almost the same with the combustion efficiency found by the Flue gas analyser with deviation of 1.89% occurred due to measurement errors.)

The efficiency of the factory boiler is found to be 77.63% which is less than the recommended design performance of furnace oil fired boiler (i.e $\geq 85\%$) [27]. This efficiency drop is due to the following reasons.

- Loss of sensible heat of the dry flue gas (54.17% of total loss and 12.12% efficiency loss of boiler)
- Loss due to the present of H_2 in fuel (loss due to latent heat) (27.12% of total loss and 6.07% efficiency loss of boiler)
- Loss due to the moisture content of combustion air (0.9% of total loss and 0.2% efficiency loss of boiler)
- Loss due to the moisture content of fuel (0.13% of total loss and 0.03% efficiency loss of boiler)
- Loss of heat by radiation and convection from boiler surface (2.27% of total loss and 0.51% efficiency loss of boiler)
- Boiler blowdown loss (15.5% of total loss and 3.47% efficiency loss of boiler)

6.7 Identified ECOs

ECOs for boiler are identified from inspection, interview, and detail energy audit conducted.

a) Housekeeping ECOs:

1. Lack of awareness on energy management to the factory workers
2. The soot is not removed with a regular time interval
3. Excessive blowdown is done by operators

4. The Boiler is working with adjusted pressure range of 8 to 11 bars. It is automatically adjusted to stand and stop at 8 and 11 bars respectively. During this, the boiler needs high fuel consumption to restart (boilers are not recommended to work in such conditions)

b) ECOs Identified from detail audit:

1. Boiler surface is not insulated
2. Most of the steam distribution systems are not insulated
3. The boiler is without economizer
4. The combustion efficiency of the boiler is low due to excess air admitted (102.1%) (beyond the recommended value of 15%)
5. Boiler feed water treatment plant is failed. As a result, the boiler operates with improperly treated feed water which leads it to energy loss.

6.8 Technical and Economic Analyses for the Proposed ECOs

6.8.1 Insulating Boiler Surface

Boiler surface temperature is high relative to the ambient temperature. As a result, boiler lost 9.63kW heat to the environment. To avoid this lose, insulating boiler surface is taken as ECO. Technically it is not a difficult task for the factory to apply this as energy management opportunity. But, it should be checked for the cost effectiveness of it.

6.8.1.1 Saving Analysis

By assuming 80% of the surface loses will be recovered by the adequate insulation, the saved energy will be 7.7kW. This saves 4820.9 liters of fuel which is equivalent with 50,185.53 Birr per year. Another basic saving while we conduct insulation is environmental saving. Emissions of greenhouse gases will reduce.

6.8.1.2 Implementation Cost

The thickness of insulation is assumed to be 40mm (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 \$3.0 per square meter
- Overhead cost is fixed at \$1.3 per square meter
- Base labor cost is \$2.2 per square meter and
- Additional labor cost is \$0.11 per R-unit per square meter

The total cost per square meter is the sum of the above mentioned costs and becomes \$6.61. The total surface of the boiler is 26.4 m². Therefore: the total cost for boiler insulation will be \$174.5 (3053.82 Birr). From this, we can decide as it is an economically feasible measure.

6.8.1.3 Payback Period

The payback period can be estimated as follows.

$$\text{Simple payback Period} = \frac{\text{Implementation Cost}}{\text{Cost Saved}} \dots\dots\dots (6.33)$$

$$\text{SPBP} = 3053.82 \text{ Birr} / 50,185.53 \text{ Birr per year}$$

$$\text{SPBP} \cong 1 \text{ month}$$

6.8.2 Installing Economizer

The factory boiler is without economizer. Economizer is recommended for boilers installed without it if the following points are fulfilled [40].

- Operating hours of boiler greater than 2500 *hr/year*,
- Stack gas flow rate greater than 6852 Kg/hr,
- 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 SALF case, the following circumstances are observed. These are:

- Operating hours of boiler is greater than 2500 hr/year (i.e. 6734.25 hr/year),
- Stack gas flow rate is greater than $6852 \frac{\text{Kg}}{\text{hr}}$ (i.e. $8694 \frac{\text{Kg}}{\text{hr}}$),
- Average stack gas temperature is lower than 232°C (i.e. 172°C),
- High excess air (i.e. 102.1%),
- Ambient temperature is in the range of 11 to 28°C (i.e. 27°C),

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.

6.8.3 Controlling Excess Air by Reducing Motor Capacity

The power rating of the blower motor of the factory boiler is 7.5kW and the load factor is 53.8% of the rated power. This implies the actual power supplied to the combustion air blower motor is 4.04kW which is much less than the rated power. Due to this, it may supply air beyond the recommended amount of excess air and this has great impact on boiler efficiency. Thus, the power supplied to the air blower motor must be reduced manually with no cost by the operators to supply the required amount of air to the boiler. Though they tried to adjust it to the recommended value, the air blower motor has a minimum capacity of sucking which is much excess. This is because, the maximum power capacity required for air blower motor and minimum power capacity of the air blower motor (now found in work) are mismatched. Due to this, unwanted excess air will be supplied to the boiler and efficiency reduction of it would happen (this is done in chapter 8 in detail).

6.8.4 Repairing Water Treatment Unit

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 also its life time. If it is technically feasible, the economic feasibility analysis will be checked as follows.

6.8.4.1 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 avoided. As a result, the saved energy can be estimated as follows.

$$\text{Energy saved} = \eta_{th}(\sum_{i=1}^6(\text{losses}) + \text{Useful heat}) - \sum_{i=1}^4 \text{Energy inputs} \quad \dots\dots\dots (6.34)$$

$$\text{Energy saved} = 0.7763(2045.63 - 1987.33)$$

$$\text{Energy saved} = 40.73 \text{ kW}$$

The total amount of energy saved by repairing the water treatment plant is 40.73kW. This heat is equivalent to saving of 25,487.42 liters and 265,324.00 Birr of fuel and money per year respectively.

6.8.4.2 Implementation Cost

The estimated cost for repairing the factory water treatment plant ranges from 20,000birr–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% [12] additional cost on the direct maximum cost of purchasing the repairing equipments for transportation and other related costs, the cost of having functional water treatment plant will be $1.47 \times 30,000 = 44,100$ Birr and the cost of having the cleaning equipments will be $1.47 \times 87,500 = 128,625$ Birr. Thus the total cost will be the sum of the two and became 172,725Birr.

6.8.4.3 Payback Period

The simple payback period for water treatment unit can be estimated as follows.

$$\text{Simple payback Period} = \frac{\text{Implementation Cost}}{\text{Cost Saved}} \quad \dots\dots\dots (6.35)$$

$$\text{SPBP} = \frac{172,725.00 \text{ Birr}}{265,324.00 \text{ Birr/year}} = 0.65 \text{ year}$$

$$\text{SPBP} \cong 8 \text{ months}$$

6.9 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 three in number) which distribute steam to the distillery columns 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 (28m for each).

6.9.1 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 pipe lines of the distillery columns can be determined from 3Eplus computer program. For 40mm insulation, the total saved money will be 25,936.08 Birr per year per pipe.

Hence:

$$\text{Saved money} = 3 \times 25,936.08 \text{ Birr/year} \dots\dots\dots (6.39)$$

Saved money = 77,808.24 Birr/year (this saved energy is without considering the environmental saving).

6.9.2 Implementation Cost

From 3Eplus computer program, the cost for 40mm insulation thickness for 28m length pipe is estimated as 14,448.78 Birr. For the three pipes the implementation cost will be 43,346.34 Birr.

6.9.3 Payback Period

The simple payback period can be estimated using equation 6.40.

$$\text{SPBP} = \text{Implementation Cost} / \text{Cost Saved} \dots\dots\dots (6.40)$$

$$\text{SPBP} = 43,346.34 \text{ Birr} / 77,808.24 \text{ Birr/year}$$

$$\text{SPBP} = 7 \text{ months}$$

6.10 Identified ECMs

Based on the above analyses, the following are ECOs are technically and economically feasible which play crucial role in improving the boiler efficiency. These include:

- 1) Insulating boiler surface,
- 2) Insulating the main steam distribution pipe lines,
- 3) Repairing water treatment plant, and
- 4) Keeping the percentage of the excess air with in the recommended range by installing a fan motor (blower motor) which has appropriate nameplate power.

CHAPTER SEVEN

7. DETAIL ENERGY AUDIT OF THE FACTORY DISTILLERS

7.1 Introduction

The distillery columns are used to evaporate alcohol from water and other solutions by heating it using super heated steam produced by the boiler. Distillation of alcohol in SALF takes place by using three columns namely distillation column, filtration column and rectification column.

The major thermal energy utilizing equipment of the factory is distillery columns. Distillery columns are energy intensive parts of the factory. Distillation column requires an average of 1400 l/h of fermented wine. Fermented wine contains $25^{\circ} - 27^{\circ}$ brix molasses syrups and other solutions. In this columns, impurities which have low boiling points than alcohol will evaporate before the boiling point of alcohol reaches and separate themselves from the alcohol solution. Impurities with higher boiling point than alcohol which demands boiling temperature above alcohol boiling point will remain as residue in the effluent. Alcohol and some impurities with boiling point around alcohol boiling point would be sent to the filter column for farther separation. This is accomplished by heating the solution up to 78°C (Alcohol boiling point). The remaining constituents are channeled to the river as an effluent with temperature of 87.38°C . After leaving the filter column, the alcohol solution passes through rectification column for further purification process to keep the expected alcoholic quality of the factory product.

7.2 Collected Data for the Distillery Columns

Data are collected with direct inspection from gauge and direct measurement using easily moveable instruments. Most of the thermal energy produced by the boiler is consumed by the distillery columns. Hence, inspection of distillation system is conducted using infrared thermometer, meter, caliper and gauge mounted on distillery system. The measured data at the distillery system include: external surface temperatures of the columns, ambient temperatures, length and diameters of the columns, steam consumption of each columns, steam pressure, and temperature of each column.

These data are presented in tables 7.1 and table 7.2.

Table 7.1 Distillation columns data

Item	Distillation Column	Filtration Column	Rectification Column	Data collection Method
Length [m]	4.94	3.90	9.46	Measured
Outside dia. [m]	0.616	0.616	0.616	Measured
Inside dia.[m]	0.6	0.6	0.6	Measured
Surface Area[m ²]	9.56	7.55	18.31	Calculated
Ambient temp. [°C]	34	33	33.3	Measured
Surface temp. [°C]	90.7	71.7	89.9	Measured
Fluid temp. [°C]	92.7	75.7	93.9	Gauge
Volume flow rate of steam[m ³ /s]	0.41	0.122	0.296	Gauge
Steam pressure [bar]	1	0.5	1	Gauge
Steam temp. [°C]	149	123	146	Measured/Gauge

Table 7-2 Distillation columns solutions data

Item	Reading	Unit	Data collection Method
Density of ethanol	790	kg /m ³	From gauge
Density of fermented wine	1455	kg /m ³	Catalogue
Temperature of fermented wine	35.1	°C	Measured
Ambient temperature of fermentation room	27.0	°C	Measured
Volume flow rate of ethanol to filter column	0.00011	m ³ /s	From gauge
Volume flow rate of fermented wine to distillation	1400	l / hr	From gauge

column			
Temperature of the effluent	87.38	°C	Measured
Ambient (datum) temperature	27.0	°C	Datum

7.3 Energy Performance Analysis of Distillery Columns

To perform energy performance analysis for continuous operation process (not batch process) of distillery columns, the following parameters must be determined.

- Mass flow rate of fermented wine,
- Mass flow rate of steam for each columns,
- Mass flow rate of effluent,
- Specific heat of fermented wine, and
- Specific heat of effluent.

7.3.1 Mass Flow Rate Calculations

7.3.1.1 Steam Mass Flow Rate

The volume flow rate, temperature and pressure of steam input to each column are tabulated in table 7.1. Using the gage temperature and pressure of the steam, the density of steam is determined using standard steam table. The mass flow rate of the steam is calculated by multiplying volume flow rate of the steam by the density. The mass of steam supplied to each column is calculated using the following equations. Mass flow rate of steam consumed by distillation column:

$$\dot{m}_{s(\text{dist})} = \dot{V}_{s(\text{dis.})} \times \frac{1}{V_{@1\text{bar and } 149^{\circ}\text{C}}} \dots\dots\dots (7.1)$$

$$\dot{m}_{s(\text{dist})} = 0.41 \frac{\text{m}^3}{\text{s}} * 0.4104 \frac{\text{Kg}}{\text{m}^3} = 0.168 \frac{\text{Kg}}{\text{m}^3}$$

Mass flow rate of steam consumed by filtration column:

$$\dot{m}_{s(\text{filt})} = \dot{V}_{s(\text{filt.})} \times \frac{1}{V_{@0.5\text{bar and } 123^{\circ}\text{C}}} \dots\dots\dots (7.2)$$

$$\dot{m}_{s(\text{filt})} = 0.122 \frac{\text{m}^3}{\text{s}} * 0.3604 \frac{\text{Kg}}{\text{m}^3} = 0.044 \frac{\text{Kg}}{\text{m}^3}$$

Mass flow rate of steam consumed by rectification column:

$$\dot{m}_{s(\text{rect})} = \dot{V}_{s(\text{filt.})} \times \frac{1}{V_{@1\text{bar and } 146^\circ\text{C}}} \dots\dots\dots (7.3)$$

$$\dot{m}_{s(\text{rect})} = 0.296 * \frac{\text{m}^3}{\text{s}} * 0.4018 \frac{\text{Kg}}{\text{m}^3} = 0.119 \frac{\text{Kg}}{\text{s}}$$

Then the total amount of steam consumed by factory distillery columns is the sum of steam consumed by each column.

$$\dot{m}_{s(\text{total})} = \dot{m}_{s(\text{dis})} + \dot{m}_{s(\text{filt})} + \dot{m}_{s(\text{rect})} \dots\dots\dots (7.4)$$

$$\dot{m}_{s(\text{total})} = 0.168 \frac{\text{Kg}}{\text{m}^3} + 0.044 \frac{\text{Kg}}{\text{m}^3} + 0.119 \frac{\text{Kg}}{\text{s}} = 0.331 \frac{\text{Kg}}{\text{s}}$$

The mass balance of the produced steam consist of operating steam input mass and steam supplied to each distillery columns, vent steam, and steam supplied to de-aerator as output mass.

Total amount of fermented wine sent to distillation column from fermented wine tank is 1400lit/hr.

Therefore, the total mass flow rate of fermented wine can be:

$$\dot{m}_{\text{wine}} = \dot{V}_{\text{wine}} * \rho_{\text{wine}} \dots\dots\dots (7.5)$$

But:

$$\dot{V}_{\text{wine}} = 1400 \text{ l/h}$$

$$\dot{V}_{\text{wine}} = 1400 \frac{1}{\text{h}} * \frac{10^{-3} \text{ m}^3/\text{l}}{3600\text{s/h}} = 0.0004 \frac{\text{m}^3}{\text{s}} \text{ and}$$

$$\rho_{\text{wine}} = 1455 \frac{\text{Kg}}{\text{m}^3} [7]$$

Hence substituting the above data in equation (7.5) and the mass flow rate of fermented wine is equals to:

$$\dot{m}_{\text{wine}} = \dot{V}_{\text{wine}} * \rho_{\text{wine}}$$

$$\dot{m}_{\text{wine}} = 0.0004 \frac{\text{m}^3}{\text{s}} * 1455 \frac{\text{Kg}}{\text{m}^3} = 0.582 \frac{\text{Kg}}{\text{s}}$$

7.3.1.2 Ethanol Mass Flow Rate

Total amount of alcohol sent to filtration column from distillation column is 386.40lit/hr.

Therefore, the total amount of mass flow rate of alcohol can be calculated by multiplying the volume flow rate by its density.

$$\dot{m}_{\text{alc}} = \dot{V}_{\text{alc}} * \rho_{\text{alc}} \dots\dots\dots (7.6)$$

But: $\dot{V}_{\text{alc}} = 386.40 \text{ l/h}$

$$\dot{V}_{\text{alc}} = 386.40 \frac{1}{\text{h}} * \frac{10^{-3} \text{ m}^3/\text{l}}{3600\text{s/h}} = 0.00011 \frac{\text{m}^3}{\text{s}} \text{ and}$$

$$\rho_{\text{alc}} = 790 \frac{\text{Kg}}{\text{m}^3} [7]$$

$$\dot{m}_{\text{alc}} = 0.00011 \frac{\text{m}^3}{\text{s}} * 790 \frac{\text{Kg}}{\text{m}^3} = 0.085 \frac{\text{Kg}}{\text{s}}$$

7.3.1.3 Effluent Mass Flow Rate

Direct measurement of flow velocity of an effluent is impossible. Because no gauge is mounted to the pipe used to remove the effluent from the distillery. As a result, the effluent mass flow rate can be estimated by equating mass in and mass out in columns are equal. This is done by assuming the leakage observed in the distillery columns is insignificant.

$$\dot{m}_{\text{s(total)}} + \dot{m}_{\text{wine}} = \dot{m}_{\text{eff}} + \dot{m}_{\text{alc}} \dots\dots\dots (7.7)$$

$$\dot{m}_{\text{eff}} = (\dot{m}_{\text{s(total)}} + \dot{m}_{\text{wine}}) - \dot{m}_{\text{alc}}$$

Substituting the results of equations (7.4), (7.5), and (7.6) in (7.7) and the mass flow rate of effluent will is:

$$\dot{m}_{\text{eff}} = (\dot{m}_{\text{s(total)}} + \dot{m}_{\text{wine}}) - \dot{m}_{\text{alc}}$$

$$\dot{m}_{\text{eff}} = (0.331 \frac{\text{Kg}}{\text{s}} + 0.582 \frac{\text{Kg}}{\text{s}}) - 0.085 \frac{\text{Kg}}{\text{s}} = 0.828 \frac{\text{Kg}}{\text{s}}$$

7.3.2 Specific Heat Calculations [7]

7.3.2.1 Effluent

The specific heat of effluent during the distillation of alcohol is given by

$$C_{P(\text{effl})} = (3.14 + 0.000025(T_{\text{effl}} - T_{\text{am}})) \dots\dots\dots (7.8)$$

Where: T_{effl} = Effluent temperature = 87.71 °C

T_{am} = Ambient temperature = 25 °C

$$C_{P(\text{effl})} = (3.14 + 0.000025(T_{\text{effl}} - T_{\text{am}}))$$

Hence: $C_{P(\text{effl})} = (3.14 + 0.000025(87.71 \text{ °C} - 25 \text{ °C})) = 3.142 \text{ kJ/kg}^\circ\text{C}$

7.3.2.2 Fermented Wine

The specific heat of fermented wine is determined by substituting the values of temperature of fermented wine instead of temperature of the effluent in equation (7.8).

Therefore the specific heat of fermented wine is given by.

$$C_{P(\text{wine})} = (3.14 + 0.000025(T_{\text{wine}} - T_{\text{am}}))$$

Where:

T_{wine} = Wine fermentation temperature = 35.1°C

T_{am} = Ambient temperature = 27 °C

Substituting the above data in equation (7.11) the specific heat of the fermented wine is given

$$C_{P(\text{wine})} = (3.14 + 0.000025(35.1^\circ\text{C} - 27^\circ\text{C})) = 3.1402$$

7.4 Energy Analysis of the Distillery Columns

To perform the thermal energy audit of the distillery columns and thereby obtain the net energy loss from the distillation process, thermal energy analysis of the distillery columns must be conducted.

The energy analysis is based on the energy input and output of the distillery columns.

All the input-output energy of the distillery is as shown in figure 7.1.

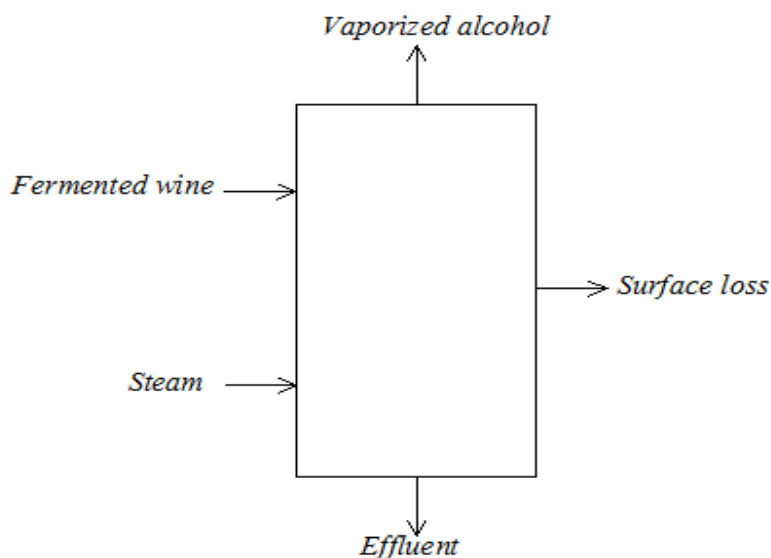


Fig. 7.1 Input output energies of distillery columns

7.4.1 Input Energy

As illustrated in figure 7.2, steam and fermented wine are the only inputs of the distillery columns which supply the required energy for the process performed in the columns. These two energy sources of the distillery columns are discussed below.

7.4.1.1 Steam Energy

The major energy source of the distillery columns is steam energy. The amount of heat energy supplied to the distillery columns can be calculated by multiplying the mass flow rate of steam to each column by its enthalpy. The input steam energy can be obtained using equation (7.9).

$$Q_{(i)s} = \dot{m}_{(i)s} * h_{(i)gs} \dots\dots\dots (7.9)$$

Where:

$Q_{(i)s}$ = Steam energy to the distillery columns

$\dot{m}_{(i)s}$ = Mass flow rate of steam to columns

$h_{(i)gs}$ = Enthalpy of super heated steam at a given temperature and pressure

Substitute the values of $\dot{m}_{(i)s}$ and the corresponding $h_{(i)gs}$, and the results are summarized in the following table.

Table 7-3 Input steam energy in distillation columns

Columns	Steam $\dot{m}_{(i)s}$ [Kg] [s]	Temp. [°C]	Pressure [bar]	Enthalpy $h_{(i)gs}$ [KJ] [Kg]	Heat input [KW]
Distillation	0.1683	149	1	2774.40	466.93
Filtration	0.044	123	0.5	2715.90	119.50
Rectification	0.1189	146	1	2768.38	329.16
Total					915.59

7.4.1.2 Energy from the Fermented Wine

The energy of fermented wine is the enthalpy of fermented wine by virtue of its temperature elevation relative to the ambient temperature of fermentation room. The enthalpy of fermented wine due to its temperature elevation from the ambient temperature fermentation temperature can be obtained using the following equation (7.10).

$$Q_{\text{wine}} = \dot{m}_{\text{wine}} * C_{P(\text{wine})} (T_{\text{wine}} - T_{\text{am}}) \dots\dots\dots (7.10)$$

Where:

Q_{wine} – Energy of fermented wine

$$\dot{m}_{\text{wine}} - \text{Mass flow rate of fermented wine} = 0.582 \frac{\text{Kg}}{\text{s}}$$

$$C_{P(\text{wine})} - \text{Specific heat of fermented wine} = 3.1402 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}}$$

$$T_{\text{wine}} - \text{Fermentation temperature} = 35.1^\circ\text{C}$$

$$T_{\text{ambient}} - \text{Ambient temperature} = 27^\circ\text{C}$$

Substituting the above data in equation (6.10) input energy due to fermented wine is given:

$$Q_{\text{wine}} = 0.582 \frac{\text{Kg}}{\text{s}} * 3.1402 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}} (35.1^\circ\text{C} - 27^\circ\text{C})$$

$$Q_{\text{wine}} = 14.80 \text{ kW}$$

7.4.2 Output Energy

The energy losses associated with the distillation of alcohol in the distillery columns is indicated in figure 7.2 include energy loss due to effluent, column surfaces, and heat used to evaporate alcohol

7.4.2.1 Energy Loss due to Effluent

The energy loss due to effluent leaving the distillation column can be obtained using the mass flow rate of effluent and enthalpy change of effluent at effluent temperature relative to the ambient temperature. The analysis is executed using equation (7.11).

$$Q_{\text{effl}} = \dot{m}_{\text{effl}} * C_{P(\text{effl})} (T_{\text{effl}} - T_{\text{am}}) \dots\dots\dots (7.11)$$

Where:

$$Q_{\text{effl}} - \text{Energy loss with the effluent}$$

$$\dot{m}_{\text{effl}} - \text{Mass flow rate of effluent} = 0.828 \frac{\text{Kg}}{\text{s}}$$

$$C_{P(\text{effl})} - \text{Specific heat of effluent} = 3.142 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}}$$

$$T_{\text{effl}} - \text{Effluent temperature} = 87.38^\circ\text{C}$$

$$T_{\text{am}} - \text{Ambient temperature} = 25^\circ\text{C}$$

Substituting the above data in equation (7.11) energy loss with the effluent is given:

$$Q_{\text{effl}} = 0.828 \frac{\text{Kg}}{\text{s}} * 3.142 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}} * (87.38 - 25)^\circ\text{C}$$

$$Q_{\text{effl}} = 162.29 \text{ kW}$$

7.4.2.2 Heat loss due to Radiation and Convection

As wind cruises over the distillery surface, energy will be lost from the distillery surface to the wind by convection. In addition, due to difference in temperature between the ambient air and the distillery surface, there is also radiation energy loss. The energy loss due to convection and radiation in watt per unit area of the distillery surface exposed to the ambient temperature condition is given by [25]:

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \sqrt{\frac{196.85 \cdot V + 68.9}{68.9}} \right] \right\} \frac{W}{m^2} * S_{(i)A} \dots (7.12)$$

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 + 1.957 (T_{(i)s} - T_{(i)a})^{1.25} \right] \right\} \frac{W}{m^2} * S_{(i)A}$$

Where:

$Q_{(i)s}$ – Heat loss due to radiation and convection from the distillery surface, in [W]

$T_{(i)s}$ – Surface temperature of the i^{th} distillery column, in [$^{\circ}\text{K}$]

$T_{(i)a}$ – Local ambient temperature of the i^{th} distillery column, in [$^{\circ}\text{K}$]

$S_{(i)A}$ – Surface area of the i^{th} distillery column, in [m^2]

V – Wind velocity = 0 (Since the working condition is a closed room (indoor condition), the wind velocity is approximately zero)

By substituting the corresponding values in equation (7.12), the value of $Q_{(i)s}$ can be summarized in table 7.4 as follows.

Table 7-4 Heat loss from distillery surface

Columns	Ambient temperature ($T_{(i)a}$) [$^{\circ}\text{K}$]	Surface Temperature ($T_{(i)s}$) [$^{\circ}\text{K}$]	Surface area ($S_{(i)A}$) [m^2]	Surface Heat loss ($Q_{(i)s}$) [kW]
Distillation	307.15	363.85	9.56	6.34
Filtration	306.15	344.85	7.55	3.11
Rectification	306.45	363.05	18.31	12.06
Total				21.51

7.4.2.3 Heat Needed to Evaporate Alcohol

The heat energy used to perform the evaporation of alcohol from fermented wine can be found from energy balance of heat entering and leaving the distillery columns.

Heat in steam + Heat in fermented wine = Heat in effluent + Heat loss by radiation and convection + Heat in vapor alcohol

$$Q_s + Q_{\text{wine}} = Q_{\text{eff}} + Q_{\text{surf}} + Q_{\text{alc}} \quad (7.13)$$

Rearranging equation (7.13) will give:

$$Q_{\text{alc}} = (Q_s + Q_{\text{wine}}) - (Q_{\text{effl}} + Q_{\text{sur}}) \quad (7.14)$$

Substitute the values in (7.14) and heat energy carried by evaporation of alcohol is given by:

$$Q_{\text{alc}} = (915.59 \text{ kW} + 14.804 \text{ kW}) - (21.51 \text{ kW} + 162.286 \text{ kW})$$

$$Q_{\text{alc}} = 746.598 \text{ kW}$$

7.5 Energy Sankey Diagram of the Distillery

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 calculations. This diagram represents visually various inputs and outputs including losses so that energy managers can focus on finding

improvements in a prioritized manner. The energy Sankey diagram of the distillery is drawn using the heat balance sheet above and is shown in figure 7.2 [30].

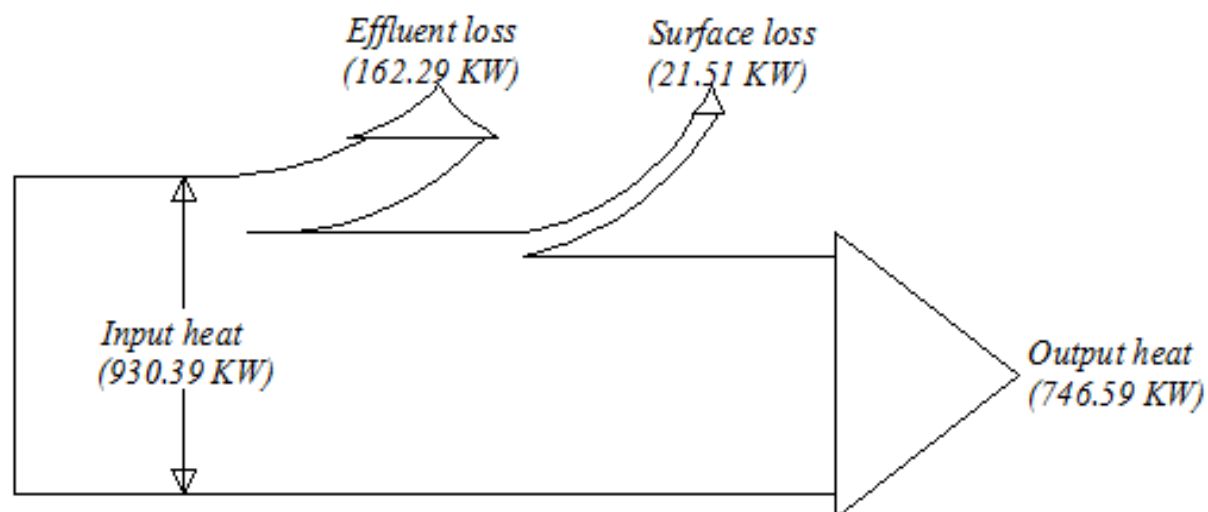


Fig 7.2 Energy sankey diagram of distillery columns

The major energy losses from distillery are surface loss and energy loss through effluent. The energy audit results of the distillery discovered that the total input heat to the distillery is 930.39kW. From this 1.73 % (16.09kW) will be lost due to radiation and convection from surfaces of distillery columns while loss due to effluent accounts 17.44% (162.27kW) of the input energy. But the recommended percentage of heat carried away by the effluent is not greater than 10% [7] of the input energy. This indicates that, the percentage of heat carried away by the effluent in the factory distillery columns is more than the recommended value.

7.6 ECOs Identified

Low cost or no cost ECOs are listed in the preliminary energy audit of distillery columns in chapter five. In addition to these, the detailed energy audit conducted for the distillery columns identified two basic ECOs. These are:

1. Insulating the distillery columns surface, and
2. Recovering heat from the hot effluent channeled to the outside environment using double-pipe heat exchanger.

These opportunities took the greater position in the detail audit of the distillery columns.

7.7 Technical and Economical Evaluation of ECOs

7.7.1 Insulating the Distillery Columns Surface

The thickness of insulation is assumed to be 40mm (adequate insulation thickness) [Scenario results of 3Eplus]. As mentioned above insulation is not much difficult task though it saves energy and environment.

7.7.1.1 Saving Analysis

By assuming 80% of the distillery surface loss will be saved, the saved energy will be 17.21 kW which is equivalent to 112,109.67 Birr per year.

7.7.1.2 Implementation Cost

The total cost per square meter is \$6.61(115.68 Birr). The total surface area of the three distillery columns is 35.42m². Therefore: the total implementation cost for insulation will be 4097.21 Birr.

7.7.1.3 Payback Period

The payback period for this measure can be calculated as:

$$\text{SPBP} = \frac{\text{Implementation cost}}{\text{Cost saved}} \dots\dots\dots (7.15)$$

$$\text{SPBP} = 4097.21 \text{ Birr} / 112,109.67 \text{ Birr} \cong 1 \text{ month}$$

7.7.2 Recovering Heat from Effluent

According to detailed energy audit of the distillery columns, 162.29kW of energy is removed away with the effluent. But most of alcohol producing factories extract heat energy from hot effluent by using double pipe heat exchangers to preheat the fermented wine and thereby reduces their steam consumption. The temperature of fermented wine will increase when we use double pipe heat exchanger for preheating fermented wine by hot effluent. Thus the factory can use double pipe heat exchanger to increase the heat gained from fermented wine. Technical and economical evaluation of the identified opportunity is discussed below by assuming counter flow type heat exchanger.

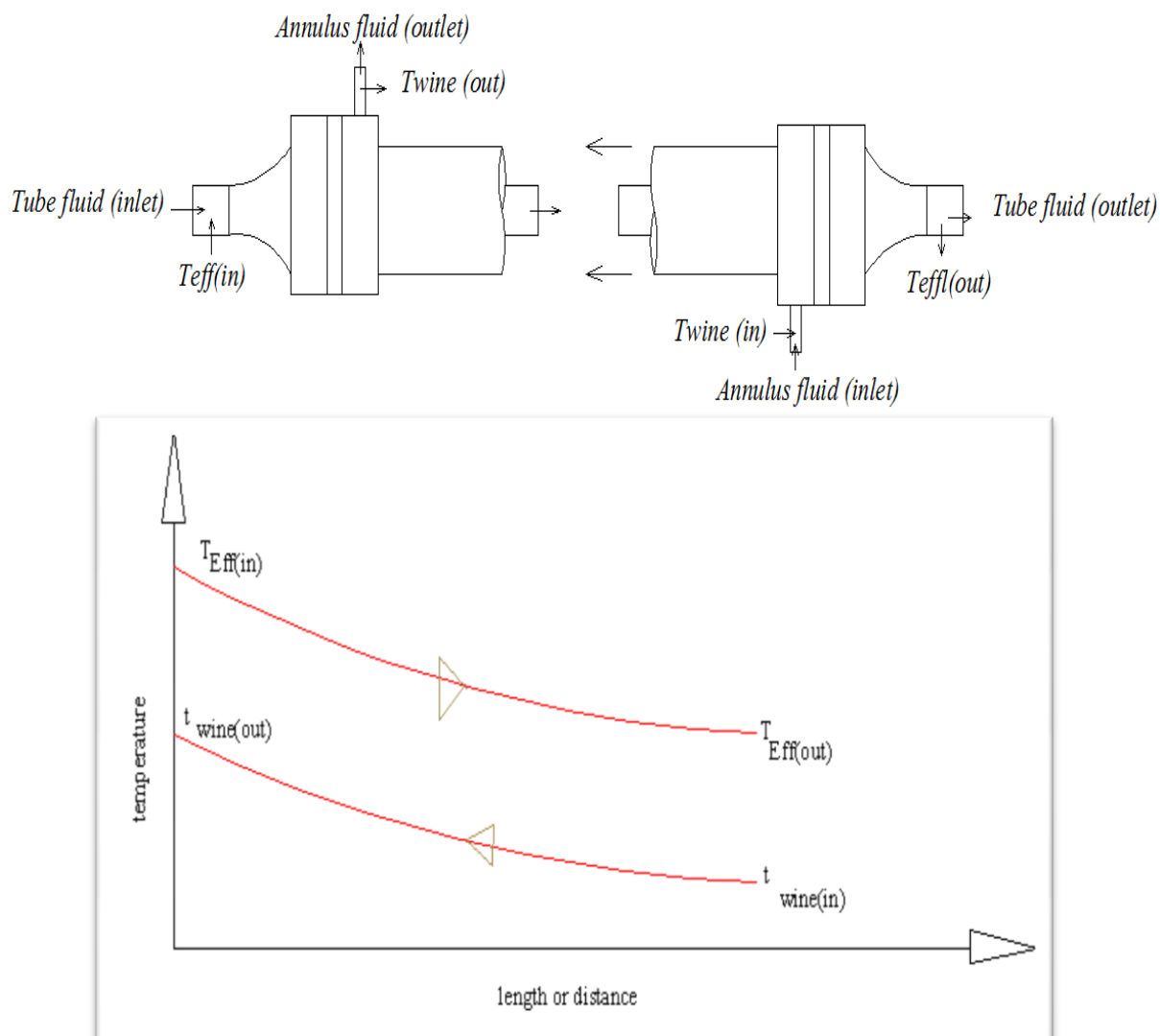


Fig. 7.3 Double Pipe Heat Exchangers

For the fermented wine, the heat transfer rate is:

$$Q_{\text{wine}} = \dot{m}_{\text{wine}} C_{P(\text{wine})} (T_{\text{wine}(\text{out})} - T_{\text{wine}(\text{in})}) \dots\dots\dots (7.16)$$

For the effluent, the heat transfer rate is:

$$Q_{\text{effl}} = \dot{m}_{\text{effl}} C_{P(\text{effl})} (T_{\text{effl}(\text{in})} - T_{\text{effl}(\text{out})}) \dots\dots\dots (7.17)$$

Assuming all heat of effluent is gained by the fermented wine and setting equations (7.16) and (7.17) equal will give:

$$\dot{m}_{\text{effl}} C_{P(\text{effl})} (T_{\text{effl}(\text{out})} - T_{\text{effl}(\text{in})}) = \dot{m}_{\text{wine}} C_{P(\text{wine})} (T_{\text{wine}(\text{out})} - T_{\text{wine}(\text{in})}) \dots\dots\dots (7.18)$$

Rearranging and introducing a new variable R:

$$R = \frac{(T_{\text{wine}(\text{out})} - T_{\text{wine}(\text{in})})}{(T_{\text{effl}(\text{out})} - T_{\text{effl}(\text{in})})} = \frac{\dot{m}_{\text{effl}} C_{P(\text{effl})}}{\dot{m}_{\text{wine}} C_{P(\text{wine})}}$$

$$T_{\text{effl(out)}} = T_{\text{effl(in)}} - R(T_{\text{wine(out)}} - T_{\text{wine(in)}}) \dots\dots\dots (7.19)$$

For counter flow, the outlet temperature of the cooler fluid (fermented wine) can be either equal or exceed the outlet temperature of warmer fluid (effluent). By assuming that, as the outlet temperature of the fermented wine and effluent are equal and rearranging equation (7.19) gives:

$$T_{\text{effl(out)}} = \frac{T_{\text{effl(in)}} + RT_{\text{wine(in)}}}{(1+R)} \dots\dots\dots (7.20)$$

Where:

$$\dot{m}_{\text{effl}} - \text{Mass flow rate of the effluent} = 0.828 \frac{\text{Kg}}{\text{s}}$$

$$\dot{m}_{\text{wine}} - \text{Mass flow rate of the wine} = 0.582 \frac{\text{Kg}}{\text{s}}$$

$$T_{\text{effl(in)}} - \text{Inlet temperature of the effluent} = 87.38 \text{ }^{\circ}\text{C}$$

$$T_{\text{wine(in)}} - \text{Inlet temperature of wine} = 35.1 \text{ }^{\circ}\text{C}$$

$$C_{P(\text{effl})} - \text{Specific heat the effluent} = 3.142 \frac{\text{KJ}}{\text{Kg}^{\circ}\text{C}}$$

$$C_{P(\text{wine})} - \text{Specific heat the wine} = 3.1402 \frac{\text{KJ}}{\text{Kg}^{\circ}\text{C}}$$

$$R = \frac{(T_{\text{wine(out)}} - T_{\text{wine(in)}})}{(T_{\text{wine(out)}} - T_{\text{wine(in)}})} = \frac{\dot{m}_{\text{effl}} C_{P(\text{effl})}}{\dot{m}_{\text{wine}} C_{P(\text{wine})}}$$

$$R = \frac{(T_{\text{wine(out)}} - T_{\text{wine(in)}})}{(T_{\text{wine(out)}} - T_{\text{wine(in)}})} = \frac{\dot{m}_{\text{effl}} C_{P(\text{effl})}}{\dot{m}_{\text{wine}} C_{P(\text{wine})}} = \frac{0.828 \frac{\text{Kg}}{\text{s}} * 3.142 \frac{\text{KJ}}{\text{Kg}^{\circ}\text{C}}}{0.582 \frac{\text{Kg}}{\text{s}} * 3.1402 \frac{\text{KJ}}{\text{kg}^{\circ}\text{C}}}$$

$$R = 1.4235$$

Substituting the above data in equation (7.20) and the outlet temperature of the effluent will be 56.67°C, thus the fermented wine temperature will be increased by 21.57°C.

Using the known mass flow rate and density of the fluids, and the economic range of fluid velocity it is possible to determine the size of the exchanger. The optimum velocity values for various fluids are given in [Appendix E]. Even if the optimum velocity value of effluent is not included in the appendix, it is possible to take the optimum value of water velocity which is (1.4 – 2.8)m/s because 90% of the effluent is water. Using the minimum and maximum velocities, the flow area can be estimated as:

$$\text{Min flow area} = \frac{\dot{m}_{\text{effl}}}{\rho_{\text{eff}} * V_{\text{max}}} \dots\dots\dots (7.21)$$

$$\text{Min flow area} = \frac{0.828 \frac{\text{Kg}}{\text{s}}}{1455 \frac{\text{Kg}}{\text{m}^3} * 2.8 \text{ m/s}}$$

$$\text{Min flow area} = 0.00020324 \text{ m}^2$$

$$\text{Max flow area} = \frac{\dot{m}_{\text{effl}}}{\rho_{\text{eff}} * V_{\text{min}}} \dots\dots\dots (7.22)$$

$$\text{Max flow area} = \frac{0.828 \text{ Kg/s}}{1455 \text{ Kg/m}^3 * 1.4 \text{ m/s}}$$

$$\text{Max flow area} = 0.00040648 \text{ m}^2$$

The maximum flow area is approximately corresponds to (2 1/2 x 1 1/4) double-pipe heat exchanger [Appendix F]. Therefore, the tube size will be:

$$\text{ID}_a - \text{Inside diameter of the annulus} = 0.06338 \text{ m}$$

$$\text{ID}_p - \text{Inside diameter of the pipe} = 0.03279 \text{ m}$$

$$\text{OD}_p - \text{Outside diameter of the pipe} = 0.03495 \text{ m}$$

$$L - \text{Length of the heat exchanger} = 3 \text{ m}$$

The economic analysis of the feasible energy conservation opportunities involves calculating the energy to be saved, the cost of implementing the energy saving opportunities and determining the payback period of the energy investment. These analyses are performed below.

7.7.2.1 Saving Analysis

From the results of the energy audit analysis performed so far, it is known that the energy gained by fermented wine at a temperature of 35.1 °C is 14.804 kW. But using a double pipe heat exchanger to preheat the fermented wine by hot effluent, the temperature of fermented wine can be brought to 56.67°C. The energy of the fermented wine that could be increased by installing a double pipe heat exchanger is given by:

$$Q_{\text{New(wine)}} = \dot{m}_{\text{wine}} * C_{P(\text{wine})} (T_{\text{wine}} - T_{\text{amb}}) \dots\dots\dots (7.23)$$

Where:

$$Q_{\text{New(wine)}} - \text{Energy gained by preheated of fermented wine}$$

$$\dot{m}_{\text{wine}} - \text{Mass flow rate of fermented wine} = 0.582 \text{ kg/s}$$

$$C_{P(\text{wine})} - \text{Specific heat of fermented wine} = 3.1402 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}}$$

$$T_{\text{wine(new)}} - \text{Fermentation temperature} = 56.67^\circ\text{C}$$

$$T_{\text{am}} - \text{Ambient temperature} = 25^\circ\text{C}$$

Substituting the above data in equation (7.23) the energy gained due to preheated fermented wine is given:

$$Q_{\text{New(wine)}} = 0.582 \frac{\text{kg}}{\text{s}} * 3.1402 \frac{\text{KJ}}{\text{Kg}^\circ\text{C}} (56.67^\circ\text{C} - 25^\circ\text{C})$$

$$Q_{\text{New(wine)}} = 57.88\text{kW}$$

Therefore, the net energy gained due to preheating of the fermented wine with the effluent will be $57.88\text{kW} - 14.804\text{kW} = 43.08\text{kW}$. The equivalent fuel and money saved is 26,953.7 liters and 381,745.25 Birr per year respectively.

7.7.2.2 Implementation Cost

The cost of a typical double pipe heat exchanger ranges from 50,000 – 60,000Birr depending on size, length and feature with an average effective life time of 10 to 15years. Adding 47% [15] additional cost on the direct average cost of purchasing the heat exchanger for transportation and other related costs, the cost of having the heat exchanger will be $1.47 \times 60,000 = 88,200\text{Birr}$. This is done by considering the maximum cost of the double pipe heat exchanger.

7.7.2.3 Payback Period

The payback period can be found by dividing the cost saved with the cost of heat exchanger.

$$\text{Simple Payback Period} = \frac{\text{Cost of Heat Exchanger}}{\text{Cost Saved}} \dots\dots\dots (7.24)$$

$$\text{SPBP} = \frac{88,200 \text{ Birr}}{547,112.921 \text{ Birr/year}}$$

$$\text{SPBP} \cong 0.23\text{year} \cong 3 \text{ months}$$

The life time of the heat exchangers is in the range of 10 to 15 years [8]. Therefore, this ECM is economically feasible.

CHAPTER EIGHT

8. DETAIL ENERGY AUDIT OF MOTORS AND PUMPS OF SALF

8.1 Introduction

Improving the efficiency of electric motors and the equipments they drive can save energy, reduce operating costs, and improve our productivity of the factory. In order to evaluate the energy performance of motors with its driven machines, different data are 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.

Though the function of air compressor in alcohol producing factories is to mix and dilute the stored molasses, in SALF in almost all inspection time of the factory, the workers used steam to mix and dilute molasses. For few time, they used the compressed air in case of insufficient steam production time.

The factory installed a three phase AC Induction motors with rated power capacities within the range of 3.3 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, 0.8318 to 0.8966, 10 to 20 years, and 365.0 hours per year to 6734.25hours per year respectively.

8.2 Performance Evaluation of Motors

To check whether the factory motors are efficient or not, performance evaluation of motors will be conducted. Energy-efficient motors should be considered in the following circumstances:

- For all new installations
- When purchasing equipment packages, such as compressors, HVAC systems, and pumps
- When major modifications are made to facilities or processes
- Instead of rewinding older, standard efficiency units
- To replace oversized and under loaded motors
- As part of a preventive maintenance or energy conservation program.

8.2.1 Data Collected

The data collecting is 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.

Table 8.1 Motors Data

Motors	Quantity	Rated values read from nameplate						Measured(Actual)			
		Current, I[A]	Voltage, V[v]	Power Factor, P.F	Power P [kW]	Speed [RPM]	Standard Eff. η [%]	Current, I[A]	Voltage, V[v]	Power, P [kW]	Power Factors, P.F
A	2	12.0	380	0.87	7.5	2930	86.4	7.47	379.7	2.32	0.78
B	1	10.9	380	0.87	6.3	3287	86.3	7.01	381.2	3.59	0.82
C	2	9	380	0.83	4.0	2860	82.9	5.60	379.6	2.52	0.83
D	1	2.8	380	0.83	4.0	1380	80.0	1.74	380.8	0.96	0.71
E	1	6.7	380	0.88	3.3	3287	85.2	4.17	379.4	2.28	0.81
F	1	25.1	380	0.87	18.5	3000	86.7	16.85	380.6	10.91	0.85
G	2	8	380	0.87	5.6	1420	85.6	4.98	379.3	1.62	0.73
H	1	20	220	0.88	5.5	2910	84.6	12.45	219.6	3.93	0.83
I	1	14.3	400	0.88	7.5	2930	86.8	7.61	400.9	5.00	0.86
J	1	7.7	380	0.83	8.48	1420	82.5	4.80	380.7	2.79	0.77

Where:

- A – Motor for boiler fuel feed pump
- B – Motor for boiler feed water pump
- C – Motor for wine feed pump to distillation column
- D – Motor for alcohol transferring pump from rectification column to temporary alcohol storage
- E – Motor for wine transferring pump from wells to decantation tank
- F – Motor for submersible pump
- G – Motor for alcohol transferring pump from temporary storage to liquor room
- H – Motor for water feed pump to bottle washing machine
- I – Motor for air compressor pump
- J – Motor for condenser feed water pump

From table 8.1, we can see 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.

8.2.2 Load Factors of Motors

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.

$$L_F = \frac{P_{\text{meas}}}{P_R} \dots\dots\dots (8.1)$$

Where:

L_F – Load factor of motors

P_{meas} – Measured Electric input power

P_R – Nameplate input power

By substituting values from table 8.1 in equation (8.1), the load factor of motors are tabulated in table 8.2.

Table 8.2 Load factors of the motors

Motor type	Rated Power [kW]	Measured input electric power of motors, P_{measured} [kW]	Calculated load factors(L_F)
A	7.5	2.32	0.31
B	6.3	3.59	0.61
C	4.0	2.52	0.63
D	4.0	0.96	0.24
E	3.3	2.28	0.67
F	18.5	10.91	0.59
G	5.6	1.62	0.29
H	5.5	3.93	0.71
I	7.5	5.00	0.66
J	8.48	2.79	0.33

The average optimum load factor of motors is 40% [29]. But, we can see from table 8.2 as the calculated load factor values for motors A, D, G, and J have load factors below the recommended value (i.e. 40%). 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.

8.2.3 Mechanical Power of Motors

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 (8.2).

$$P_{\text{mech}} = \eta_m * P_{\text{meas}} \dots \dots \dots (8.2)$$

Where:

P_{mech} –Mechanical power of motors

$P_{meas.}$ – Measured electric power of motors

η_m – Nameplate efficiency of motors

Table 8.3 Mechanical power of motors

Motors	Electric power of motors, $P_{meas.}$ [kW]	Standard Nameplate efficiency of motors, η_m [%]	Mechanical power of motors, P_{mech} [kW]
A	2.32	86.4	2.01
B	3.59	86.3	3.10
C	2.52	82.9	2.09
D	0.96	80.0	0.77
E	2.28	85.2	1.94
F	10.91	86.7	9.46
G	1.62	85.6	1.39
H	3.93	84.6	3.33
I	5.00	86.8	4.23
J	2.79	82.5	2.30

8.3 Performance Evaluation of Pumps

All pumps used in SALF are with the designed capacities of volume flow rate 3m³/h to 40 m³/h and head 30 m to 45 m. The service time and operating hours of the pumps are 8 to 12 years and 365.0 to 6734.25 hours per year respectively. The functions of factory pumps are to transfer water, fuel oil, fermented wine and alcohol 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.

8.3.1 Collected data on 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 AAiT Mechanical Engineering department Laboratory. 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.

Table 8.4 Pumps data

Pumps	Rated values			Measured data			
	Head, H[m]	Flow rate, $\dot{Q}[\text{m}^3/\text{hr}]$	Fluid densities, $\rho[\text{kg}/\text{m}^3]$	Head, H[m]	Speed, V[m/s]	Diameter of pipes, D[m]	Operating Hours
A'	40	6.5	991	4.25	0.1243	0.0508	6734.25
B'	40	9.6	1000	3.38	0.156	0.0508	6734.25
C'	40	5	1455	2.35	0.193	0.0508	6734.25
D'	45	3	790	2.91	0.135	0.0254	6734.25
E'	40	5	1455	4.45	0.241	0.0508	6734.25
F'	30	40	1000	8.70	5.46	0.0953	6734.25
G'	45	3	790	9.10	0.0498	0.0445	547.50
H'	40	5	1000	4.32	0.634	0.0508	6734.25
I'	40	5	1.24	5.53	0.47299	0.0762	365.00
J'	30	20	1000	10.81	0.07578	0.0635	6734.25

Where:

A' –Boiler fuel feed pump

B' –Boiler feed water pump

C' –Wine feed pump to distillation column

D' –Alcohol transferring pump from rectification to the temporary storage

E' – Wine transferring pump from wells to decantation tank

F' –Submersible pump (two in number)

G' –Alcohol transferring pump from temporary storage to liquor room

H' –Water feed Pump to bottle washing machine (two in number)

I' –Compressor pump

J' –Condenser feed water pump

Even if there are many pumps with their driving motors in the factory, only those having motor load factor less than 40% are included in this analysis. 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.

8.3.2 Volume Flow Rate of Fluids

The volume flow rate of the fluid is given by equation (8.3).

$$\dot{Q} = V_{\text{fluid}} * A_{\text{pipe}} \dots\dots\dots (8.3)$$

Where:

$\dot{Q}$ – Volume flow rate of fluids

V_{fluid} – Fluid flow velocity

A_{pipe} – Fluid flow pipe area for each pump = $\frac{\pi D_{\text{pipe}}^2}{4}$

Using data from table 8.4 and substituting in equation (8.3), the volume flow rate of the pump is tabulated in table 8.5.

Table 8.5 Volume flow rates of fluids

Pumps	V_{fluid} [m/s]	D_{pipe} [m]	A_{pipe} [m^2] * 10^{-4}	$\dot{Q}$ [m^3/s]
A'	12.43	0.0508	20.27	0.0252
B'	15.60	0.0508	20.27	0.0317
F'	5.46	0.09525	71.56	0.0389
G'	4.98	0.0445	15.52	0.0082
I'	47.30	0.0762	45.604	0.2157
J'	7.58	0.0635	31.67	0.024

8.3.3 Power gained by the fluid

The output power gained by pumps due to fluids passing through them is give by the following relation:

$$P_{\text{out}} = \frac{\rho * g * \Delta H * \dot{Q}}{1000} \dots\dots\dots (8.4)$$

Where:

ρ – Density of fluid

g – Acceleration due to gravity

H – Pump head

$\dot{Q}$ – Volume flow rate of fluid

Table 8.6 Power gained by fluids

Pumps	Density, ρ [Kg/ m ³]	Head, H [m]	Flow rate, $\dot{Q}$ [m ³ /s]	Flow rate, $\dot{Q}$ [m ³ /hr]	$\frac{\rho g H \dot{Q}}{1000} = P_{out}$ [kW]
A'	991	4.25	0.0252	90.72	1.04
B'	1000	3.38	0.0317	114.12	1.05
F'	1000	8.70	0.0389	140.04	3.32
G'	790	9.10	0.0082	29.52	0.58
I'	1.24	5.53	0.2157	776.52	0.02
J'	1000	10.81	0.024	5.04	2.545

8.3.4 Pump Efficiency

The efficiency of pump is given by equation (8.5).

$$\eta_p = \frac{P_{hyd}}{P_{mech}} \dots\dots\dots (8.5)$$

Where: η_p – Pump efficiency

P_{hyd} – Power gained by the fluid

P_{mech} – Mechanical power input to pump

Table 8.7 Pumps efficiencies

Pumps	Mechanical power input to pump [P_{mech}]	Power gained by the fluid [P_{hyd}]	Pump efficiency [η_p %]
A'	3.70	1.04	28.11
B'	3.32	1.05	31.63
F'	9.46	3.32	35.10
G'	2.33	0.58	24.89
I'	4.34	1.18	27.19
J'	3.41	2.55	74.78

From table 8.7, we can see that all pumps efficiency values are below the recommended value (i.e. 60%) [15] except one pump (i.e J') with efficiency 74.78%.

8.4 Overall Performance Analysis (Motors and Pumps)

In order to conduct the energy analysis and thereby find the efficiency of pumps and motors the following parameters are determinant. These include nameplate power of the motors, load factor of the motors, actual power factors of the motors, volume flow rate of the fluid, power gained by the fluid, mechanical power, pump efficiency, and 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).

$$\eta_{oa} = \frac{P_{hyd}}{P_{meas.}} \dots\dots\dots (8.6)$$

Where:

P_{out} – Power gained by the fluid

P_{meas} – Measured electric power

Using data from table 8.3 and table 8.6 and substituting in equation (8.6), the overall efficiency of motors and pumps is tabulated in table 8.8.

Table 8.8 Overall efficiencies of motors and pumps

Pumps	P_{hyd} [kW]	P_{meas} [kW]	η_{oa} [%]
A'	1.04	3.65	28.49
B'	1.05	3.29	31.92
F'	3.32	9.33	35.58
G'	0.58	2.33	24.89
I'	0.02	4.27	27.64
J'	2.545	8.48	30.00

The overall efficiencies of motors and pumps are: 28.49%, 31.92%, 35.58%, 24.89%, 27.64%, and 30%. These show as there is mismatch between the pumping system and the piping.

8.5 Identified ECOs

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.

1. Motors A, D, G, and J are working with 0.31, 0.24, 0.29, and 0.33 load factors with reference to the recommended load factor (i.e. 40%)
2. Although all the factory motors have low power factors, motors A, D, G, and J are those with lower power factors. They have P.Fs of 0.78, 0.71, 0.73, and 0.77 respectively
3. Leakages are observed in most pumps
4. Factory pumps efficiencies (resulted from mismatch between pumping systems and pipings) are low in comparison with the benchmarks

8.6 Technical and Economical Evaluation of Identified ECOs

8.6.1 Technical Evaluation of Improving Pumps Efficiencies

From the energy analyses conducted above, the efficiencies of pumps A', B', F', G', I', and J' are 28.11%, 31.63%, 35.10%, 24.89%, 27.6194%, and 74.78%. 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.

$$\text{Imbalance (\%)} \text{ for } A' = \left(\frac{Q(\text{actual}) * H(\text{actual})}{Q(\text{Designed}) * H(\text{designed})} - 1 \right) \times 100\% \dots\dots\dots (8.9)$$

Where:

Q (actual) = measured flow rate = 0.0252 m³/s

H (actual) = measured discharge head = 4.25m

Q (Designed) = required flow rate = 0.002m³/s

H (Designed) = required discharge head = 40m

Using these data and substituting in equation (8.9), the percent of imbalance will be:

$$\text{Imbalance (\%)} = \left(\frac{Q(\text{actual}) * H(\text{actual})}{Q(\text{Designed}) * H(\text{designed})} - 1 \right) \times 100\%$$

$$\text{Imbalance (\%)} = \left(\frac{0.0252 * 4.25}{0.0018 * 40} - 1 \right) \times 100\%$$

$$\text{Imbalance (\%)} = 48.75\%$$

By following the same steps for the other four pumps, the imbalances will be: 48.75%, 0.45%, 0.15%, 33.25%, and 0.37% for pumps (A', B', F', G', I') respectively.

These imply pumps may have a high bypass flow rate, or have a flow rate that varies from their best efficiency points (BEP). Such pumps can be prioritized for further analysis, according to the degree of imbalance or mismatch between actual and designed conditions. The degree of imbalance for pumps B', F' and I' are relatively very small. Hence, replacing the existing old and inefficient pumps A' and G' with new and efficient pumps are 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.

8.6.1.1 Estimation of Pump Volume Flow Rate

Pumps A' and G' operate at a volume flow rates of 90.72m³/hr and 29.52m³/hr (see table 8.2). Thus the replaced pumps flow rates should satisfy these conditions.

8.6.1.2 Estimation of Pump head

Pumps A' and G' operate at a head of 4.25m, 9.1m and 10.81m (see table 8.2). For the compensation of other minor losses 15% margin is added on heads. Therefore the heads will be 4.89m and 10.47m. Thus the replaced pump heads will also satisfy these requirements.

8.6.1.3 Estimation of pump efficiency

An average efficiency of pump is 60% [15]. Thus, the selected replaced pumps should also attain an efficiency of 60%.

8.6.1.4 Input Power of the Motor

The input power of the motors is given by:

$$P_{in} = \frac{\rho_{fluids} * g * \Delta H * \dot{Q}}{\eta_m * \eta_p} \dots\dots\dots (8.10)$$

Substituting the data in equation (8.10) for the input power of the motors is:

$$P_{in} \text{ for } A' = \frac{991 \text{ Kg/m}^3 * 9.81 \text{ m/s}^2 * 4.89 \text{ m} * 0.0252 \text{ m}^3/\text{s}}{0.864 * 0.6}$$

$$P_{in} \text{ for } A' = 2.31 \text{ kW}$$

Based on this P_{in} for pumps G' and J' are 1.296 kW and 0.36 kW respectively.

The above technical analyses indicate that as the input electric powers are decreased from 3.65 to 2.41kW, 8.48 to 1.3 kW and 2.33 kW to 0.36 kW respectively when the existing pumps are replaced with the new ones. Thus replacing the pumps are technically feasible ECOs.

8.7 Economic Evaluation

8.7.1 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 equation (8.11).

$$\text{Saved energy} = (\text{Old Pump } P_{(ele)} - \text{New Pump } P_{(ele)}) * T_{\text{Operating hours}} \dots\dots\dots (8.11)$$

Where:

For pump A' :

$P_{(ele)\text{Old Pump}}$ – Motors input powers using the existing pumps

$$P_{(ele)\text{Old Pump}} = 7.5 \text{ kW}$$

$P_{(ele)\text{New Pump}}$ – Motors input power using the new pump

$$P_{(ele)\text{New Pump}} = 2.41 \text{ kW}$$

$T_{\text{Operating hours}}$ – Operating hours of pumps

$$T_{\text{Operating hours}} = 6734.25 \text{ hours}$$

Substituting the above data in equation (8.11), and then the saved energy is 34,277.33 kWh/year.

Using $P_{(ele)\text{Old Pump}} = 2.33 \text{ kW}$, $P_{(ele)\text{New Pump}} = 1.29 \text{ kW}$ and $T_{\text{Operating hours}} = 547.5 \text{ hours}$ and following the above steps for pump G' , 13,113.38 kWh/year will be saved.

Thus, the saved cost can be determined by multiplying saved energy by the energy cost.

$$SC = SE * \text{Cost} \left(\text{Birr/kWh} \right) \dots\dots\dots (8.12)$$

Where:

SC – Cost saving

Cost (Birr/kWh) – cost per kWh = 0.4993 birr/kWh (average electric cost for the audit year)

Substituting the above data in equation (8.12), will give saved costs of 17,114.67 Birr/year and 6547.62 Birr/year respectively.

8.7.2 Implementation Cost Analysis

The cost of pumps is approximately 10,000 Birr. The payback period can be found by dividing the cost saved with the cost of pump. Adding 10% additional cost on the direct average cost of purchasing the pump for transportation, installation and other related costs [45]. The cost of the pump will be:

$$CP = 1.1 * \text{initial Cost of Pumps}$$

$$CP = 1.1 * 10,000 = 11,000 \text{ Birr}$$

Payback period will be:

$$SPBP = \frac{CP}{SC} \dots\dots\dots (8.13)$$

For pump A':

$$SPBP = \frac{11,000}{17,114.67} \text{ year} = 0.643 \text{ year} (\cong 8 \text{ months})$$

Following the same steps, the SPBP for pump G' will be 1.68 years. The approximate life time of the pump is 10 years. Therefore: replacing fuel feed pump and condenser feed water pump are economically feasible energy conservation opportunities.

8.6 Feasible ECOs

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

CHAPTER NINE

9. ENERGY ACTION PLAN

9.1 Introduction

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

9.1.1 Short term Action Plan

This plan requires no/or least capital investment or least improvement to avoid energy wastages and minimizing non essential energy users and can be accomplished in a short period of time on a regular basis never less than once a year. This plan can be implemented quickly without the need for additional studies to improve the system efficiency.

9.1.2 Medium Term Action Plan

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

9.1.3 Long Term Action Plan

The long term plan is done once to achieve efficiency improvement through innovation, planning and engineering input. More capital investment which thoroughly studied is required to finalize the long term action plan.

9.2 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 lead by an energy team leader or manager, and consists of all professionals who have brief knowhow about all energy related information of the factory.

Table 9-1 Action Plan of ECMs

No.	Recommended ECOs	Energy action term
1	Create valid awareness about energy utilization to the factory workers in formal and regular way	Short term
2	Blow soot from the boiler regularly	Short term
3	Remove scale from boiler waterside regularly	Short term
4	Check the proper functioning of steam traps in each shift and replace the defective	Short term
5	Clean the boiler surface and room from dirt	Short term
7	Hang the lamps to the proper place	Short term
8	Turning off lights when not needed	Short term
9	Reduce the illumination of lamps to minimum necessary levels	Short term
10	Open compressed air distribution line valves when it is needed to remove unwontedly sucked materials	Short term
11	Regularly clean the electric motors from dirt	Short term
12	Regularly remove scale from distillery columns	Short term
13	Mount on calibrating instruments to the distillery columns	Short term

14	Seal the pumps properly to avoid leakages	Short term
15	Use compressed air instead of steam to mix molasses	Short term
16	Replace the cooling tower water pump	Medium term
17	Replace old and incandescent lamp	Medium term
18	Installing the pumps in the rooms where they are in need to function	Medium term
19	Clean the shell of the boiler at least at mid of operation year	Medium term
20	Install power measuring instrument for major electrical devices	Medium term
21	Insulate steam distribution lines to distillery columns	Medium term
22	Purchase portable energy instruments like combustion analyzer, thermo meter, flow meter, etc... to monitor the energy efficiency of the plant regularly	Long term
23	Replace the under loaded motors with appropriate sized motors (D and J)	Long term
24	Replace in inefficient pumps (A and G)	Long term
25	Repair the existing water treatment plant	Long term
26	Install double pipe heat exchanger to recover heat from effluent	Long term

CHAPTER TEN

10. CONCLUSION AND RECOMMENDATIONS

10.1 Introduction

The specific energy of the factory was determined using different data collected by inspection through walk, 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 chapter the major ECMs are recommended with respective saved energy, cost of saved energy, implementation cost, and payback periods.

10.2 Conclusions

The factory uses thermal and electric energy inefficiently. As a result, this thesis dealt with the unwise energy consuming enduse devices of SALF and attained its objectives. The enduse devices were examined for their energy performance during the assessment time and ECOs for the major energy consuming systems (Boiler, Distillery Columns, Pumps and motors) are identified. The major findings of the thesis as ECOs in SALF 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,
- Waste heat with the effluent from distillery columns,
- Operation of motors with low load factors (alcohol transferring pump motor from rectification to temporary storage and condenser feed water pump motor)
- Using oversized in efficient pumps (boiler fuel feed pump and alcohol transferring pump from temporary storage to liquor room), and
- Using energy consuming equipments beyond their recommended life time 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 ECOs.

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. These include:

10.2.1 Repairing the Existing Water Treatment Unit

The feed water of the boiler in 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 water side of the boiler and results boiler shell energy loss of 31.90kW. To avoid this, repairing water treatment plant and using mechanical cleaning equipment are the identified measures. The evaluation shows:

- Energy saved = 29.05 kW
- Cost of Energy saved = 257,446.18 Birr/year
- Implementation cost = 172,725 Birr
- Payback period is 6 months.

10.2.2 Control the Excess Air by reducing Fan motor capacity

The power rating of the fan motor of the factory is 7.5kW and it is functioning with 4.28kW to supply excess air of 102.1%, 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 = 34,277.33 kWh/year
- Cost of Energy saved = 17,114.67 Birr/year
- Implementation cost = 11,000 Birr
- Payback period is 8 months.

10.2.3 Insulating Boiler Surface

The factory boiler is not insulated. Due to this, energy has lost from the boiler surface. To avoid the surface loss, insulating is taken as ECM and the result of the analysis showed:

- Energy saved = 7.7 kW

- Cost of Energy saved = 50,185.53 Birr/year
- Implementation cost = 3053.82 Birr
- Payback period is 1 month.

10.2.4 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 = 77,808.24 Birr/year
- Implementation cost = 43346.34 Birr
- Payback period is 7 months.

10.2.5 Insulating the Distillery Columns Surface

The detail energy audit on distillery columns finds out insulating the distillery columns as a feasible ECM and the economic analysis results:

- Energy saved = 17.21kW
- Cost of Energy saved = 112,109.67 Birr/year
- Implementation cost = 4097.21Birr
- Payback period is 1 month.

10.2.6 Using Heat Recover System from Effluent

According to detailed energy audit of the distillery columns of SALF, 176.71kW of energy is removed away with the effluent. But most alcohol producing factories extract heat energy from the hot effluent by using heat exchangers for preheating the fermented wine to reduce their distillery steam consumption. Based on this fact, installing a double pipe heat exchanger to recover energy loss due to hot effluent is taken as ECO and it is feasible in both technical as well as economical analysis and the conducted economic analysis showed as follows.

- Energy saved = 61.74 kW
- Energy cost saved = 547,112.92 Birr/year
- Implementation cost = 88,200.00 Birr
- Payback period is 2 months.

10.2.7 Replacing Alcohol Transferring Pump from Temporary Storage to Liquor Room

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

- Energy saved = 13,113.38 kWh/year
- Energy cost saved = 6547.62 Birr/year
- Implementation cost = 11,000 Birr
- Payback period is 1.68 years.

10.2.8 Housekeeping (No /Low Cost) ECOs

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

- Giving updated awareness on energy management to the factory workers
- Periodic removal of soot from boiler chimney
- Periodic removal of scale from the boiler waterside
- Cleaning all machines in the factory regularly
- Covering the top open surface of distillers, fermentation tanks, and yeast propagation tanks
- Checking the proper functioning of steam traps regularly and replace the failed ones
- Replacing the worn-out valves
- Avoiding steam leakage from distribution system
- Avoiding leakage from pumps
- Using compressed air instead of steam to dilute molasses

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 alcohol manufacturer industry.

10.3 Recommendations

This thesis recommended many major ECMs from the conducted detail energy audit for different system units and many housekeeping energy conservation measures so as 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 ECMs based on the prepaid 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.

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APPENDIX A

ALCOHOL PRODUCED IN THE AUDIT YEAR

Months	Type produced Liquor		Amount of alcohol produced(Liter)
July	1	Superment 890c.c	105,013.77
	2	Jin 250c.c	9840.00
	3	Superment 250c.c	5310.00
	4	Pure Alcohol	7158.00
	5	Esat Alcohol	2113.00
	Total		132,434.77
August	1	Aprative 890c.c	64,468.04
	2	Derib Areki 890c.c	16,719.54
	3	Fernit 890c.c	15,722.74
	4	Ananas Areki 890c.c	8,291.24
	5	Jin 250c.c	15,002.50
	6	Pure Alcohol	41,525.00
	7	Esat Alcohol	9,435.00
	Total		171,164.06
September	1	Ananas Areki 890c.c	9,536.35
	2	Lome areki 890c.c	18,504.88
	3	Superment 890c.c	72,169.21
	4	Auzo Areki 890c.c	7,623.74
	5	Jin 250c.c	14,488.00
	6	Pure Alcohol	44,909.00
	7	Esat Alcohol	8,800.00
	Total		176,031.18
	1	Ananas Areki 890c.c	24,700.17
	2	Aprative 890c.c	6,715.94

October	3	Superment 890c.c	37,518.84
	4	Auzo Areki 890c.c	35,856.32
	5	Jin 250c.c	30,265.00
	6	Pure Alcohol	33,751.00
	7	Esat Alcohol	10,548.00
	Total		179,355.27
November	1	Ananas Areki 890c.c	21,949.18
	2	Superment 890c.c	58,535.30
	3	Aprative 890c.c	12,761.71
	4	Lome Areki 890c.c	18,991.71
	5	Jin 250c.c	7,320.00
	6	Auzo Areki 250c.c	3,750.00
	7	Superment 250c.c	19,085.00
	8	Pure Alcohol	26,483.00
	9	Esat Alcohol	13,415.00
	Total		182,290.90
December	1	Superment 890c.c	31,805.04
	2	Aprative 890c.c	32,535.73
	3	Lome Areki 890c.c	27,631.83
	4	Derib Areki 890c.c	39,860.43
	5	Jin 250c.c	13,265.00
	6	Superment 250c.c	10,401.00
	7	Pure Alcohol	50,879.00
	8	Esat Alcohol	10,040.00
	Total		216,418.03
January	1	Lome Areki 890c.c	11,637.64
	2	Fernit 890c.c	25,283.12
	3	Jin 250c.c	22,645.00
	Total		59,565.76

February	1	Superment 890c.c	95,222.88
	2	Aprative 890c.c	6,554.85
	3	Jin 250c.c	33,770.00
	4	Pure Alcohol	19,517.00
	5	Esta Alcohol	3,000.00
	Total		158,064.73
March	1	Superment 890c.c	94,100.59
	2	Aprative 890c.c	41,354.74
	3	Jin 250c.c	34,555.00
	4	Pure Alcohol	53,530.00
	5	Esta Alcohol	13,505.00
	Total		237,045.33
April	1	Superment 890c.c	40,593.79
	2	Lome Areki 890c.c	71,572.02
	3	Jin 250c.c	26,590.00
	4	Pure Alcohol	43,800.00
	5	Esta Alcohol	10,545.00
	Total		193,100.00
May	1	Superment 890c.c	53,793.38
	2	Aprative 890c.c	76,741.14
	3	Ananas Areki 890c.c	18,996.16
	4	Jin 250c.c	20,475.00
	5	Superment 250c.c	14,422.50
	6	Perno 890c.c	4,970.65
	7	Buna Areki 890c.c	2,947.68
	8	Pure Alcohol	46,187.00
	9	Esta Alcohol	13,970.00
	Total		252,503.51

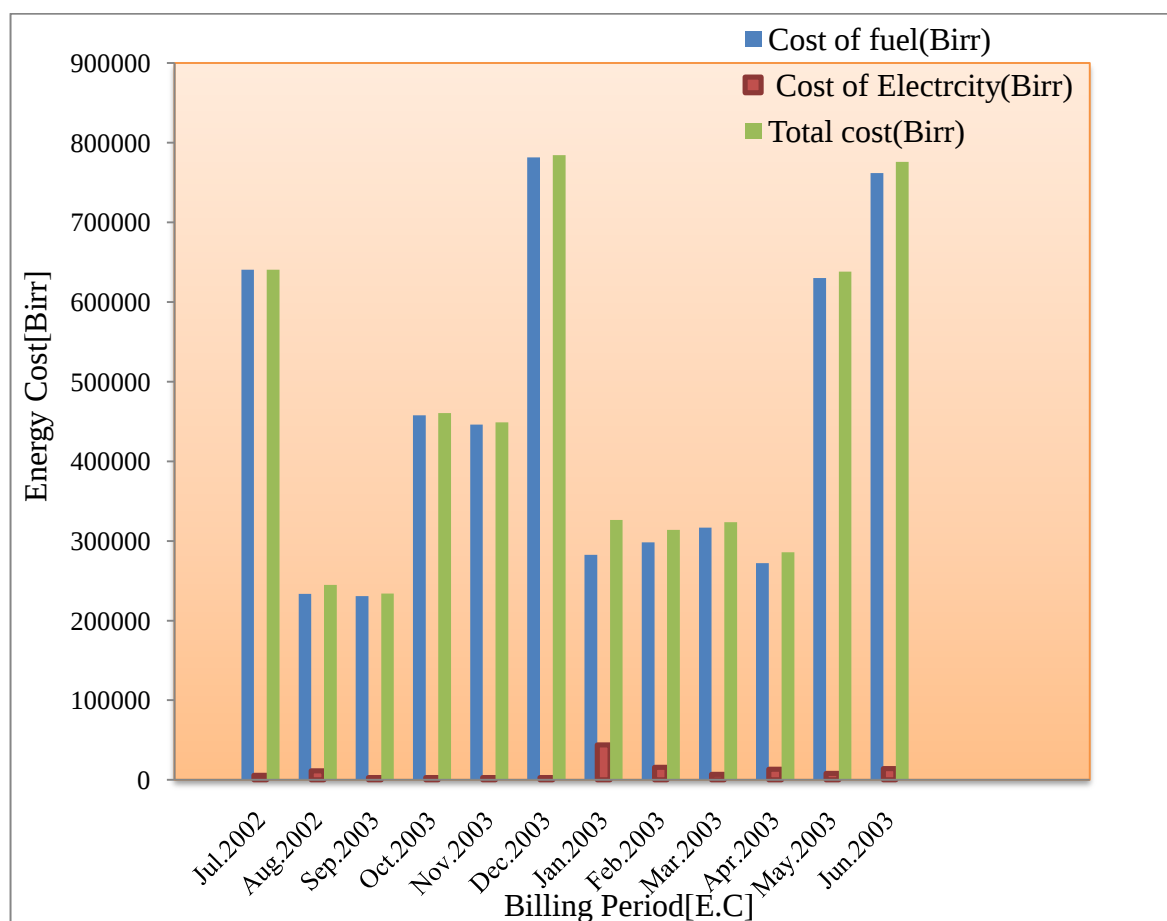
APPENDIX B

MONTHLY FUEL AND ELECTRICITY USED AT SALF IN THE AUDIT YEAR

Month	Monthly fuel consumption [Liter]	Monthly electricity consumption [kWh]
July 2002	61531.93	10604.71
August 2002	22427.74	10950.79
September 2003	22167.46	6124.84
October 2003	43963.2	5661.95
November 2003	42843.27	5661.95
December 2003	7508770	5661.95
January 2003	27137.99	2672.85
February 2003	28664.52	6770.89
March 2003	30414.46	10121.93
April 2003	26160.19	7180.09
May 2003	60535.73	16030.64
June 2003	54620.42	10132.73

APPENDIX C

MONTHLY ENERGY COSTS OF SALF FOR THE FISICAL YEAR



APPENDIX D

LIST OF MEASURING INSTRUMENTS USED

1. Combustion Analyzer, [Model: KM9104]
2. Infrared Thermometer with Laser Pointer, [Model: 42525A]
3. Easy View Dual K Thermometer, [Model: EA10]
4. Anemometer
5. Caliper
6. Meter

APPENDIX E

DATA FOR DOUBLE-PIPE HEAT EXCHANGER

VARIOUS FLUID VELOCITIES FOR ECONOMIC DIAMETER TUBES

Fluid	Economic velocity range [m / s]
Acetone	1.5 - 3.0
Ethyl alcohol	1.5 – 3.0
Methyl alcohol	1.5 – 3.0
Propyl alcohol	1.4 - 2.8
Benzene	1.4 - 2.8
Carbon disulfide	1.3 – 2.6
Carbon tetrachloride	1.2 – 2.4
Castor oil	0.5 – 1.0
Chloroform	1.2 – 2.4
Decane	1.5 – 3.0
Ether	1.5 – 3.0
Ethylene glycol	1.2 – 2.4
R-11	1.2 – 2.4
Glycerine	0.43 – 0.86
Heptane	1.5 – 3.0
Hexane	1.6 – 3.2
Kerosene	1.4 - 2.8
Linseed oil	1.5 - 3.0
Mercury	0.64 – 1.3
Octane	1.5 – 3.0
Propane	1.7 – 3.4
Propylene	1.7 – 3.4
Propylene glycol	1.4 – 2.8
Turpentine	1.4 – 2.8
Water	1.4 – 2.8

APPENDIX F

DOUBLE-PIPE HEAT EXCHANGER TUBE COMINATION AND GEOMETRY FACTORS

Type M Tubing								$A_a[m] = \pi OD_p L [ft^2]$ for L =		
Size	ID _a [m]	ID _p [m]	OD _p [m]	A _p [m ²]	A _a [m ²]	D _h [m]	D _e [m]	3m	4.5m	6m
2x1 ¹ / ₄	0.05102	0.03279	0.03493	0.0008444	0.001086	0.01609	0.03959	0.3292	0.4938	0.6584
2 ¹ / ₂ x 1 ¹ / ₄	0.06338	0.03279	0.03493	0.0008444	0.002196	0.02845	0.08007	0.3292	0.4938	0.6584
3x2	0.07572	0.05102	0.05398	0.002044	0.002214	0.02174	0.05223	0.5087	0.7631	1.017
4x3	0.09998	0.07572	0.07938	0.004503	0.002901	0.0206	0.04654	0.7481	1.022	1.496