ENERGY AUDIT OF MEKANISSA ALCOHOL FACTORY

By
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EXECUTIVE SUMMERY

Mekanissa Alcohol Factory use furnace oil and electricity as primary source of energy to generate thermal and electric energy to pursue its routine alcohol production. All the thermal energy developed by the boiler is used to evaporate alcohol in the distillery columns. Most of the electricity is used to power different electrically driven systems of the factory. Both the fuel and electricity consumption patterns of the factory are known and are variable from one month to the other. The consumption of fuel was large for month of Jan, 1999 E.C (audit time) which is 649,711.82 litres and the consumption electric energy was large for the month of May, 1998 E.C (audit time) which is 57,765.88 kWh. The unit price of furnace oil and electricity on local market (audit time) are 4.1653 Birr/litre and 0.34 Birr/kWh respectively.

The nine energy systems of the factory were inspected to identify energy conservation opportunities (ECO_S) and major energy consuming systems of the factory. Out of the nine energy systems, the boiler, distillery columns and pumps, air compressor and their prime movers were found to be major energy consuming systems.

To perform the energy audit of these major energy consuming systems, different data were collected by using portable instruments, the instruments installed on major energy systems, nameplate and referring factory log sheet & record book. Using these data pre-energy audit analyses on calorific value of furnace oil, combustion property of the furnace and property of steam were investigated and results were obtained. The NCV of furnace oil used is 39,261.235kJ/kg and the excess air in the boiler was found to be 102%.

Standard energy analysis methods were used to perform the energy audit of the boiler, distillery columns, pumps & air compressor and their prime movers. Using these standard methods, the energy balance was conducted to determine the first law efficiency of the boiler and the corresponding Sankey diagram. The result obtained indicated that 1st Law efficiency of the boiler was 74.71% by direct method. This signifies that 25.29% of energy on GCV of the furnace oil was lost. The 1st Law efficiency of the boiler on heat balance method is found to be 76.1%. But the recommended efficiency of a furnace oil fired boiler is about 85% [26]. This signifies that the efficiency of the factory boiler is lower. From the results obtained in the energy audit, the combustion efficiency of furnace is low due to so many factors. One among them is the excess air admitted, which is greater than the recommended value of 15% [4]. The energy audit result also

shows the mismatch of steam supply and demand in the factory. The designed capacity of the boiler is to produce a steam of $3 ton/hr$ @ $8\ bar$ & $175\ ^{O}C$, but the factory need is $2.13 ton/hr$ max@$1\ bar$ & $150\ ^{O}C$. This shows that the factory boiler is over sized. Among various energy conservation opportunities (ECO_S) identified, replacing the boiler by a proper sized boiler was given the first priority. For replacing the existing boiler with a proper sized, technical and economical analyses were conducted, and the total amount of fuel oil and cost saving per year is 258,957.27 litre and 1,078,634.5 Birr respectively. The energy saving obtained through repairing the water treatment plant and controlling the excess air of the boiler is 7.2% of input energy, with the total fuel cost saving of 560,363.44Birr per year. The simple payback period of implementing these energy conservation opportunities (ECO_S) are very short i.e. less than a year.

Nomenclature

ρ	Density
Q	Heat energy
p	Pressure
h	Enthalpy
γ_A	Humidity factor
T	Temperature
R	Gas constant
η	Efficiency
ϕ	Relative humidity
C_P	Specific heat
$\dot{V}$	Volume flow rate
$\dot{m}$	Mass flow rate
w	Unit weight of gas
υ	Specific volume
V	Voltage
I	Current
$Cos\phi$	Power factor

Subscripts

w	Feed water
f	Fuel
b	Blowdown
s	Steam
th	Thermal
eff	Effluent
comb	Combustion
a	Atmospheric
fg	Vaporization of water
H_2O	Water

List of Figures

List of Tables

TABLE OF CONTENTS

CHAPTER 1

1 INTRODUCTION TO THE THESIS RESERCH

1.1 Background and Justification

Had it not been for existence of energy, life would have been an illusion. Human beings have been aided by energy to pass through intricate social, economic and political events in different eras. The industrial revolution in the 19th century had taken advantage of energy without which it wouldn't have been realized. The era of information in which we are found now is the indicator of how energy can be used by transforming it from one form in to another.

When we talk about energy, things would be more clear if we have a look at the sources of energy, and the way they are used. Although the sun is the ultimate sources of energy, human beings haven't significantly applied the direct radiant energy to perform their daily socioeconomic activities. Rather, most countries get their large proportion of energy demand from imported none renewable energy sources. Some of these energy sources include petroleum, natural gas and coal. The ever-dynamic demands of energy extracted from such sources led to the use of them at an unprecedented rate and hence fostered the depletion of these resources. Now, an energy gap will be created when these stored energy sources are exhausted as a result of the mutual effect of the population boom and increased reliance of human life on energy. Due consideration and careful solution are needed as the skyrocketing cost of conventional fuels, political instabilities in the Middle East related to the supply of petroleum and environmental pollution due to uncontrolled release of solid, liquid and gaseous pollutants are becoming the major problems and threats linked to energy extraction, development and use.

Of paramount importance to combat these problems and threats are enduring search for the alternative sources of energy, the proper management and conservation of the existing sources of energy, and keeping the environment from pollution. The alternative sources of energy should, as much as possible, be of low cost, exploited for long time and environmentally harmless. We have to persist on properly managing and conserving the already existing energy sources so that the exhausting of these sources will be delayed.

Energy conservation is unthinkable without efficient utilization of energy, which reduces the wastage of energy. Therefore efficient utilization should be strictly followed as it slows down additional need of energy. Hence, whether the energy consuming systems use conventional or renewable energy, priority should be given for the energy conservation, which will enable to minimize the ever-growing energy demand. So, it is unquestionable that the conservation of energy should remain to be the routine task of all energy consuming sectors so that the demand of energy gets decreased. The strict application of energy auditing together with the energy conservation measures is so indispensable to bring the wastage, demand and cost of energy to the optimum level.

Industrialized countries including France, Germany, Italy, Japan, the United Kingdom and the United State have significantly reduced their primary energy use per unit of GDP over the last three decades by practicing energy auditing and energy policy. The decline in energy costs has been driven largely by improved energy efficiency in end-uses such as vehicles, appliances, spaces heating and industrial processes [31].

As a result of low efficiency of the energy consuming equipments and machineries, excessive ventilation, inadequate insulation and lack of knowledge on energy conservation, there will be a tremendous loss of energy in the energy consuming sectors of our country. The improper usage of energy, which result in energy wastage and necessitate energy auditing in our country, will be dealt next.

Households Sector

As most people of our society belong to the lower stratum, they use wood; cow dung and those who can afford it use kerosene to accomplish energy consuming activities such as cooking, lighting etc. Few use electricity and fossil fuels whereas the large majority uses biomass for energy needs (as well as for housing contraction), which results in deforestation. To improve our household energy usage, we should teach the community at large to take energy conservation measures.

Commercial Sector

The usage of electricity and fossils is intensified here as compared to the household areas. But still much has to be done to create awareness in our society on the importance of energy conservation to save a great deal of energy that is wasted due to improper management.

Transportation Sector

Most cars in our country are old and hence their rate of fuel consumption is high. Besides, most of the streets and highways on which they run are not asphalted which contributes its own share in extra loss of energy.

Industrial Sector

The industries in our country fulfil their primary and secondary energy requirements from electric energy and fossil fuel. The mechanical equipments used by our industries are more or less obsolete that their energy consumption is high. 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 would mean that the society is overburdened by them and need an urgent means to be arbitrated. To address the above mentioned problems of the society, it deserves careful analysis of the energy effectiveness and efficiency of the machineries industrial equipment and transportation means to ensure whether they are energy efficiency or not.

As a matter of fact the energy auditing of the machineries and automobiles and the associated energy costs and patterns of energy utilization should be conducted in our household, commercial, transportation and industrial sectors. This will help us to depict the energy demand of our nation by clearly defining what our energy consumption rate would look like recently and in the forthcoming years.

1.2 Objectives of the Thesis Research

This thesis revolves around the energy audit of one of our alcohol refining factories, which is the Mekanissa Alcohol Refining Factory. The factory is situated in the southwest area of the metropolis. The product of the factory alcohol is being used as a raw material in many areas of chemical industries. These include: pharmaceutical purpose, hospital service, production of plastic materials, mixing fuel products, fabrication of paints, production of synthetic rubber, laboratory service, heating purpose, etc.

Even though the factory product has high market demand the factory is known to operate with loss in 2004/5 fiscal year due to the fact that the factory uses inefficient energy consuming systems [factory document]. The alcohol factory is old and has so many problems related to energy. The main energy related problems of the factory are, the boiler is oversized, the water treatment plant is not functional, unknown air-fuel ratio of the boiler, unknown combustion and thermal efficiency of the furnace and the boiler. Moreover the steam distribution lines are not well insulated and even some steam distribution lines are bare, excessive vent of live steam with significant amount is visible and the effluent at a temperature of 90°C is simply channelled to the river. In addition to the mentioned problems the factory has no energy management policy and its overall energy management is poor. These problems signify that there are high probabilities of energy conserving opportunities in the factory. Therefore it is absolutely essential for the factory to conduct energy auditing. Hence this thesis research examines the energy consumption pattern of the factory & efficiency of the major energy consuming systems and devices thereby identifies energy conservation opportunities to save energy and prepare energy audit documentations for the factory.

1.2.1 General Objectives of the thesis Research

The general objective of this thesis research is to examine the way energy is being used in Mekanissa Alcohol Refining Factory, and identify energy conservation opportunities so as to reduce energy costs and prepare an energy & documentation to implement cost effective energy utilization changes.

1.2.2 Specific Objectives of the Thesis Research

- To clearly identify the types of energy and cost of energy use of the factory
- To understand how that energy is being used and possibly wasted
- To indicate better energy conserving opportunities by assessing the efficiency of its energy consuming devices.
- To examine energy consuming systems of the factory so the improvements can be quantified in terms of both energy and cost: obtain Sankey diagram of the energy use
- To identify and analyze improved operational techniques and / or new equipments that could substantially reduce energy use, energy determine which ones are cost-effective
- To prepare an energy action plan

1.3 Methodology

The methods employed to achieve the objectives of the research are:

1) Literature review
2) Preliminary data collection of the factory
3) Inspection of factory energy consuming systems and equipment

4) Perform desktop analysis
5) Identify feasible Energy Conservation Opportunities (ECOs)
6) Perform technical feasibility of the identified (ECOs)
7) Perform economic analysis of the identified (ECOs)
8) Prepare list of recommended energy conservation measures (ECOs)
9) Prepare action plan

1.4 Definition and Types of Energy Audit

1.4.1 Definition of Energy Audit

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management programmed [29].

As per the Energy Conservation 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".

1.4.2 Types of Energy Audit

Depending on function and type of industry, depth to which final audit is needed, and potential and magnitude of cost reduction desired energy audit can be classified in to the following two types.

- Preliminary energy audit
- Detailed energy audit

The energy conservation act requires the energy audit report to contain recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption. The conduct of energy audit and implementation of its recommendation on cost-benefit basis through accredited energy auditors is expected to help the designated energy consumers to achieve significant reduction in their energy consumption levels.

1.4.2.1 Preliminary Energy Audit

Preliminary audit methodology is a relatively quick exercise:

- Establish energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely and the easiest areas for attention
- Set a 'reference point'
- Identify immediate (especially no-/low-cost) improvements/ savings
- Identify areas for more detailed study/measurement
- Use existing or easily obtained data

1.4.2.2 Detailed Energy Audit

A detail audit evaluates the major energy using systems using energy balance based on an inventory of energy using systems, assumptions of current operating conditions and calculation of energy use. From industry to industry the metrology of detail energy audit is flexible and is carried out in the following three phases.

Phase I Pre-Audit

Step 1

- Organize energy audit team
- Organize instrument and time frame
- Familiarization of process or facility activities

Step 2

- Conduct brief meeting /awareness program with all divisional head and person concerned

Phase II Audit Phase

Step 3

- Primary data gathering:
    - Products/service of the facility
    - Process flow diagram and energy utility diagram
    - Identify major energy systems of the facility

Step 4

- Conduct survey and monitoring:-Measurement

Step 5

- Analysis of energy use:-Energy and material balance and energy lost/waste analysis

Step 6

- Identification and development of energy conservation opportunities (ECO_S)

Step 7

- Conduct cost benefit analysis
  - -Conduct technical feasibility
  - -Conduct economical feasibility

Step 8

- Prepare energy action plane
  - Prioritize promising ECO_S for implementation
  - Prepare action plan by low, medium and long term measures

Step 9

- Reporting and presentation to the top management

Phase III Post Audit Phase

Step 10

- Implementation and follow up

1.5 Organization of the Thesis

This thesis research paper is organized in to 10 chapters which are all necessary report arrangements of energy audit. In Chapter 1 discusses the need of conducting energy audit, the general and specific objectives of the thesis research and the meaning of energy audit, types and methodology.

Chapter 2 presents brief introduction of Mekanissa Alcohol Factory including: its location, weather information, organizational structure, staff profile, the utility used by the factory and operating hours.

In Chapter 3 the main alcohol production process and the energy input of the factory is discussed.

Chapter 4 deals with the 12 months factory energy bill, energy consumption patterns of other industries (benchmark) analyzed the energy bill in terms energy intensity, comparing the energy intensity of the factory with the benchmark.

Chapter 5 presents the preliminary energy audit inspection of the major energy systems of the factory to discover no/low cost energy conservation opportunities (ECO_S) and major energy systems of the factory that required detail energy audit analysis.

In Chapter 6 discussed the detailed energy audit of the boiler to discover its energy conservation opportunities.

The detailed energy audit of the distillery system is discussed in Chapter 7 in order to investigate its energy conservation opportunities.

Chapter 8 present the detailed energy audit of pumps & air compressor with their prime movers.

In Chapter 9 summarises technically and economically feasible energy conservation recommendations and categorized them on short, medium and long term energy action plans for post audit phase analysis.

Chapter 10 presents the conclusion, recommendations for future work of the thesis research. In addition to the above described chapters the paper contains reference and five separate appendixes.

CHAPTER 2

2 INTRODUCTION TO MEKANISSA ALCOHOLFACTORY

2.1 Introduction

Mekanissa alcohol factory is a governmental organization which produces potable alcohol. The alcohol factory was initially established in 1965 by an Armenian citizen in Addis Ababa. Some parts of the factory were built in an area of 25,000 square meters which was granted by the government of Ethiopia. Just after the emergence of new regime in 1966 E.C; all the private industries and companies were nationalized including this alcohol factory.

Between the year 1967 and 1968 E.C, the government completed the whole factory in which some parts of the factory were under construction during the previous regime.

The Mekanissa Alcohol Factory has been producing alcohol for 30 years and currently it has a distillation capacity of 2,600,000 litres of alcohol per year. This implies the factory has an average production capacity of 8,666 litres of alcohol per day. The factory is still operating with originally installed old machineries and few of them are replaced with new ones which results in low performance and high risk of production hamper.

Figure 2.1 Aerial view of the factory

2.2 Geographical Location of the Factory

Mekanissa Alcohol Factory is located at the south west of Addis Ababa at an elevation of about 1,300 ft above sea level. It is situated at 500m from the Vatican Embassy along the same highway.

2.3 Weather Condition of the Factory

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 some how uniform temperature throughout the year. The pattern of rainfall is bimodal and at average 1000 mm per year. The average monthly maximum and minimum air temperatures are 17.9°C and 15°C, respectively. The coolest month is October, during which the mean daily maximum and minimum air temperatures are 23.2^0C and 8.5°C, respectively. The atmospheric pressure of the location is about 96kPa. The monthly average relative humidity is 85% and 63% for the maximum and minimum, respectively; the upper and lower limits of relative humidity are 91% in August and 52% in January, respectively.

2.4 Organizational Structure of the Factory

Mekanissa Alcohol Factory is administrated under National Alcohol & Liquor Factory that operates four alcohol and liquor factory namely: Mekanissa Alcohol Factory, Maichew liquor factory, Akaki Alcohol Factory and Sebeta Alcohol & Liquor Factory.

The factory has three departments, namely production, logistics and human resource development and administration departments, and eight divisions. The organizational structure of the factory is summarized in Figure 1.2.

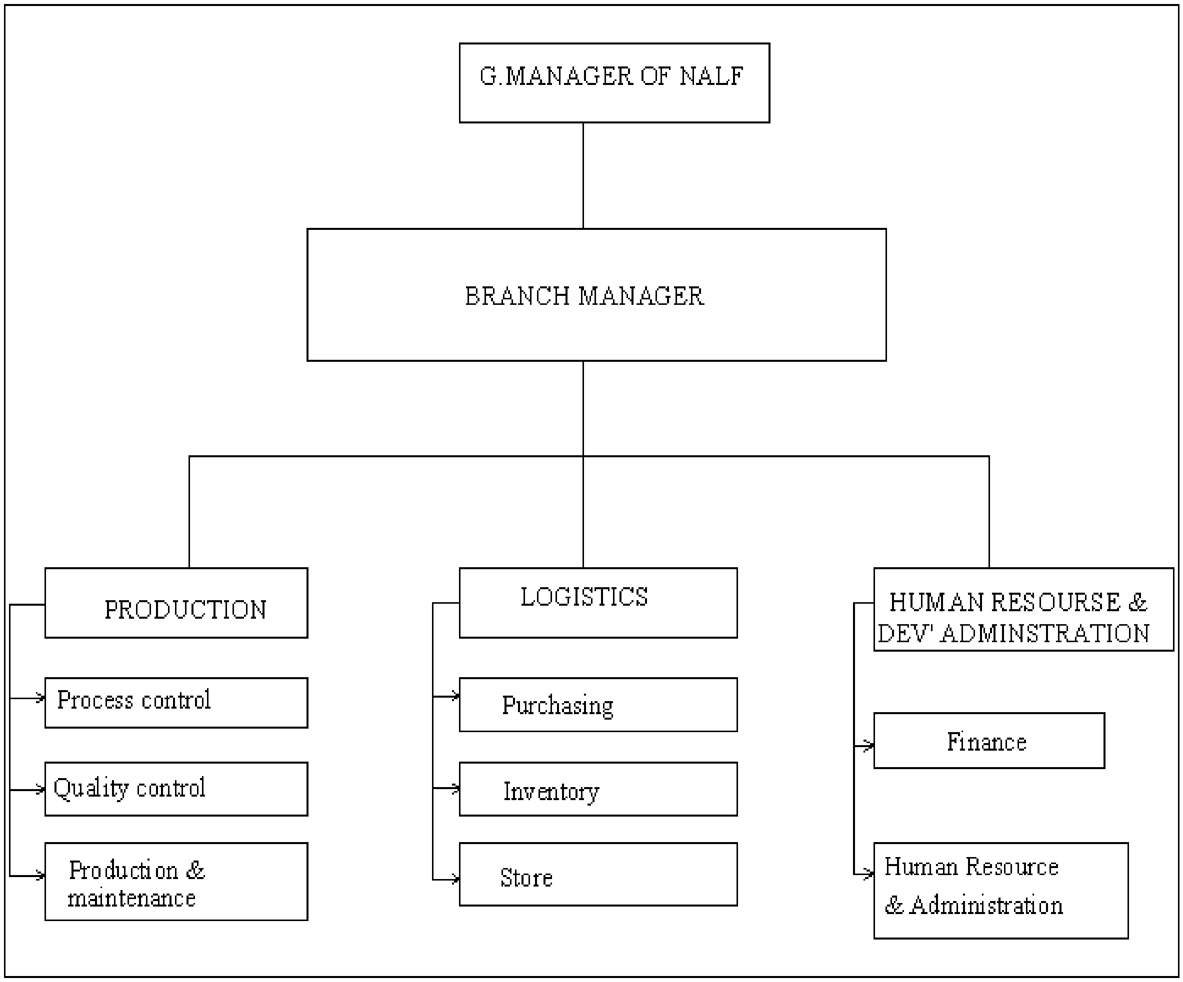

Figure 2.2 Organization structure of the factory

2.5 Staff Profile of the Factory

The total employee of the factory is 127 with the following details; 36 administration (staff), 80 permanent employees' for production and 11 temporary production labourers.

2.6 Utilities

The utilities which the factory uses are water for dilution of molasses and other factory utilization, electric energy for electric appliance and furnace oil for boiler.

2.6.1 Water Usage

The only water source for Mekanissa alcohol factory is city tap water line. The factory consumes an average of 30,000 m^3 of water per annual for molasses dilution, steam production and washing tankers and other purpose.

2.6.2 Fuel Usage

The major fuel supplier of the factory is National Oil Company (NOC). The factory purchases an average of 1,800 m^3 of furnace oil per annual from its supplier. The main use of this furnace oil is for producing steam in the boiler.

2.6.3 Electricity Usage

The factory uses an average of 57,600 kWh of electricity per month from national grid. The main use of this electricity to operate electrical appliances, such as pumps, air compressor fans etc. in the factory.

2.7 Operating Hours of the Factory

The factory operates for 12 month per annum, 24 hours in a day with three shifts namely morning, afternoon and night shifts of 8 hours operation time.

CHAPTER 3

3 ETHANOL PRODUCTION PROCESS AND THE ENERGY INPUT

3.1 Introduction

The raw material which is used for producing ethanol is molasses purchased from Wonji Sugar Factory. The procedure and process required for the production of ethanol from molasses include dilution of 80^{O} brix molasses in to 25^{O} brix and 15^{O} brix molasses syrups, propagation of yeast to facilitate the fermentation process and fermented wine is separated from sludge. By distillation of fermented wine, ethanol can be produced and collected. The energy required to perform these process are thermal energy and electrical energy. The detail procedures and process of ethanol production of the factory are discussed below. Flow diagram of alcohol production is shown in Figure 3.1.

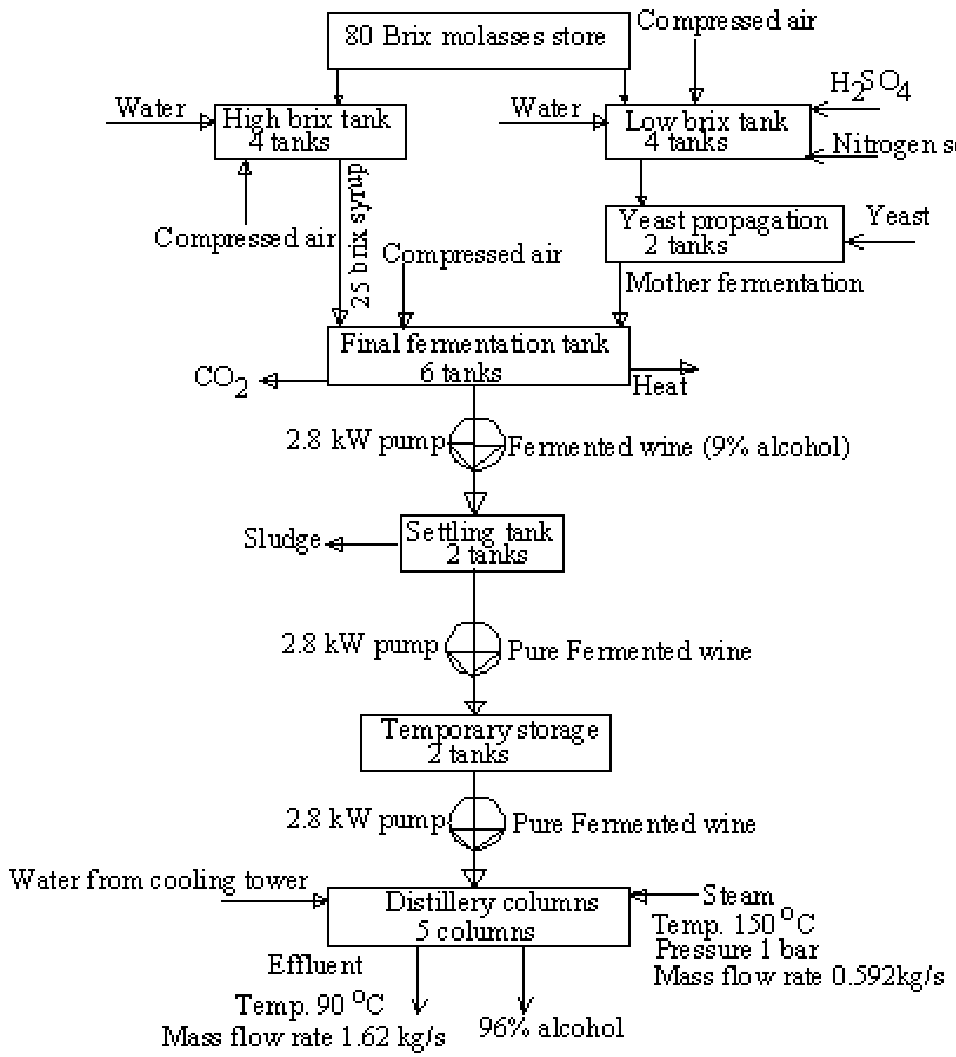

Figure 3-1 Production Flow Diagram of Alcohol

3.2 The Production Process

The main raw material used for the production of ethanol in MAF is molasses. It is a by-product of sugar factories and is cheaply available. In comparison to other sugar products, it is easy and comfortable for handling and usage. That is why it is used in many countries for ethanol production. Molasses with black & brown colour has 50% of sucrose by mass, average 45-50% alcohol content and 78-83 brix. Brix is a measure of the amount of sucrose present in the molasses. For example $80^{O} brix$ molasses contain $\frac{80*50}{100} = 40\%$ of sucrose by mass.

MAF purchases the raw materials (molasses) from Wonji Sugar Factory and transports to the factory and stores in a molasses room. The molasses store room is found at a relatively higher elevation of the factory compound. Most of the time the molasses flows to the preparation tankers by gravity. During winter and at nighttimes, the molasses is made to flow with the help of a 5kW pump.

Figure 3.2 Factory Molasses Store

3.3 Preparation of Molasses Syrup

Preparations of molasses syrup are classified into two types namely low brix molasses syrup and high brix molasses syrup.

3.3.1 Preparation of Low Brix Molasses Syrup

Low brix molasses syrup is prepared by diluting the raw $80^{O} brix$ molasses with water in the preparation tanker until the molasses brix reduces to $15^{O} brix$. The brix is continuously controlled by the chemist, and add concentrated H_2SO_4 with the ratio of 1:200 litre to reduce the PH of the syrup from 8 to 4.5. In addition to sulperic acid, 10kg of nitrogen solutions ($HPO_4(NH_3)_2$) +

$(NH_3)_4(SO_4)_3$ are added in 4,000 litre of the syrup to preserve food for yeast when the syrup is transferred to the mother fermentation tanks. Finally the syrup is agitated by compressed air and transferred to mother fermentation tanks with the help of gravity.

3.3.2 Preparation of High Brix Molasses Syrup

High brix molasses syrup is prepared by diluting the raw $80^{O}brix$ molasses with water in the preparation tanker until the molasses brix reduces to 25^{O} brix. Like low brix the brix is control by the chemist. Finally the syrup is agitated by compressed air and transferred to main fermentation tanks with the help of gravity.

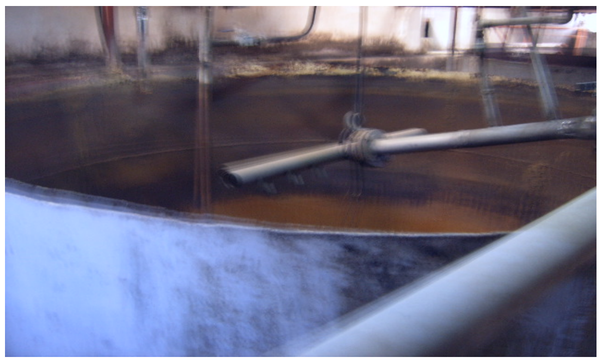

Figure 3.3 Molasses Syrup Preparation Tanks

3.4 Mother Fermentation

It is a batch process used for yeast propagation. The maximum duration of the yeast to propagate in this tank is 48 hours. To propagate yeast, first small amount of yeast is reproduced in the factory laboratory and then mixed with $15^{O}brix$ molasses syrup in the mother fermentation tanks. As yeast is easily infected by the bacteria, mother fermentation tanks must be properly washed by liquid soap to sterilize before mixing the yeast and the syrup. This process is very essential for final fermentation as well as alcohol production of the factory. The following properties of the solutions (yeast + low brix molasses syrup) are continuously controlled by the chemist.

- Sugar content of the solution
- Nitrogen content of the solution
- Acidity of the solution
- Temperature of the solution
- The presence of air in the solution

3.4.1 Sugar Content of the Solution

The sugar content of the solution which is a mixture of yeast and low brix molasses syrup must be within the range of 15 to 17 brix of molasses. If the brix size of the solution is greater than the specified range, the sugar content of the solutions increases and as a result the alcohol content of the produced wine rises. To protect the death of yeasts, the alcohol content is limited to 9% by diluting the solution with water. On the other hand, the brix size of the solution is less than the specified range, the sugar content of the solution decreases and as a result the alcohol content of the produced wine reduces. The yeast will be exposed to bacteria infection and to protect this phenomenon by adding $80^{O} brix$ molasses in order to limit the alcohol content to 9%.

3.4.2 Nitrogen Content of the Solution

Nitrogen solution is useful for the propagation and growth of yeast. This solution contains mixtures such as Bi-ammonium phosphate, Ammonium sulphate, and it is important to use other useful substances. The proper amount of nitrogen solutions within 4,000litre of low brix molasses syrup is 10 kg. The deficiency of nitrogen substance during mother fermentation process may cause distorted growth and decreases in their duty. On the other hand, excessive nitrogen substance results in the emergence of newly created cells and there will be wastage of sugar, which in turn decreases the alcohol product from a limited molasses.

3.4.3 Acidity of the Solution

In order to create favourable condition for propagation of yeast and unfavourable condition for bacteria, the acidity of the mother fermentation process must be in the range of 4 - 4.5 PH. This PH value is attained by adding concentrated sulperic acid (H_2SO_4) in the low brix molasses syrup with the proportion of 1:200 litre.

3.4.4 Temperature of the Solution

The favourable temperature for the propagation of yeast is 25 ^{O}C to 30 ^{O}C and the fermentation processes by itself exerts heat. The temperature should be regulated not to exceed the maximum temperature. Excess temperature of the fermentation process is reduced by cooling the processes with water. Excessive temperature in the process may result in the following disadvantages:

- Waste of alcohol in the form of vapour,
- Create favourable condition for the reproduction of bacteria,

- The yeast becomes weak and that sugar cannot be converted to alcohol. Hence if the temperature exceeds above the specified limit the fermentation tanks should be controlled by cooling with water.

3.4.5 Air Content in the Solution

As mother fermentation process is aerobic respiration, enough amount of air is needed for yeast propagation. Thus the air provided is equivalent with the quantity of yeast needed. If the air provided is above the limit, new cells will be produced and result in wastage of excess sugar that decreases the alcohol content that could be obtained from a limited amount of molasses. In addition to this, provision of air below the required amount will make the yeasts not to reproduce in proper quantity which can easily be infected with bacteria.

3.5 Final Fermentation

It uses batch process to complete the process. During the mother fermentation, yeasts which are propagated in a good condition constitute 10% (by volume) of the fermentation tanker and are undertaken by properly mixing with high brix molasses.

Alcohol is produced by biochemical change of yeast and sugar during its final fermentation. During the fermentation or biochemical process alcohol and carbon dioxide are produced. This process can be described by the following chemical reaction.

$$High\ brix\ molasses\ syrup + Yeast \Rightarrow Alcohol + CO_2 + Heat$$

This process is passed through three different phases in different tanks i.e. pre-fermentation, main-fermentation and supplementary-fermentation in order to complete its process.

3.5.1 Pre- Fermentation

During the mother fermentation, yeast is reproduced with a minimum carbon dioxide level and without foam formation. Most of the sugar is used by the yeast formation and as a result its alcohol content becomes low. The duration of this fermentation process depends on the amount of yeast transferred from mother fermentation tankers. If large amount of yeast is transferred from mother fermentation, the duration of the fermentation process will be short. The maximum duration of the syrup in this tank is 24 hours. Than it is transferred to the main fermentation tank by gravity.

3.5.2 Main Fermentation

During this fermentation process, the amount of CO_2 increases and as a result the foam will have different thickness depending on the preservation time in the main fermentation tank. Since the reaction is fast, the alcohol content increases during this process. At this time it is important to control the temperature by cooling the fermentation tanker with water because the temperature in the tank should not exceed 30 ^{O}C. The maximum duration of the syrup in this tank is 48 hours. Than it is transferred to supplementary fermentation tanks by gravity.

3.5.3 Supplementary Fermentation

During this fermentation process, movement of the syrup is decreased in the tankers that are to say the duration should be short. As the duration increases, the syrup can be infected with bacteria. If the brix amount is similar for two consecutive times with in three hours, the bacteria will have a tendency to react easily in the tanker. Therefore movement in the tanker is stopped immediately and it is transferred to the decantation tankers by a 2.8 kW pump.

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Figure 3.4 Fermentation Tankers

3.6 Fermented Wine Settling and Temporary Storage

This step is used as temporary storage for fermented wine that has completed its fermentation process. Its additional purpose is to settle the solid and semi solid particles that are mixed with the fermented wine to drain it. For quality purposes the wine transferred from the tankers to the distillery column is 5/6th of the total volume, where as the amount to be drained is 1/6th of the total volume. The transfer of fermented wine takes place by two pumps which are driven by motors of capacity 2.8 kW each.

3.7 Distillation Process

Distillation is one of the major production processes of ethyl alcohol. It is the processes of boiling different mixtures, at different boiling points, in different columns and condensing the evaporation in order to separate one form the other by fractional distillation. And then the high boiling point fluid will remain at the bottom, the upper goes to the condenser and is cooled partially. This partially cooled fluid again goes to the top of other column. This process is called reflux. The boiling point of alcohol is 78.2 ^{O}C but the boiling point of water is 100 ^{O}C. The low boiling point and high volatile property makes alcohol to be easily distilled from water. The process of refining alcohol is called fractional distillation. There are different chemical by products during fermentation such as acetic acid, Aldehyds, and high alcohol ester. If the presence of these chemicals is above the limit, they will cause harmful effects including negative impact in the quality of alcohol produced. Therefore, they are removed in different columns during distillation.

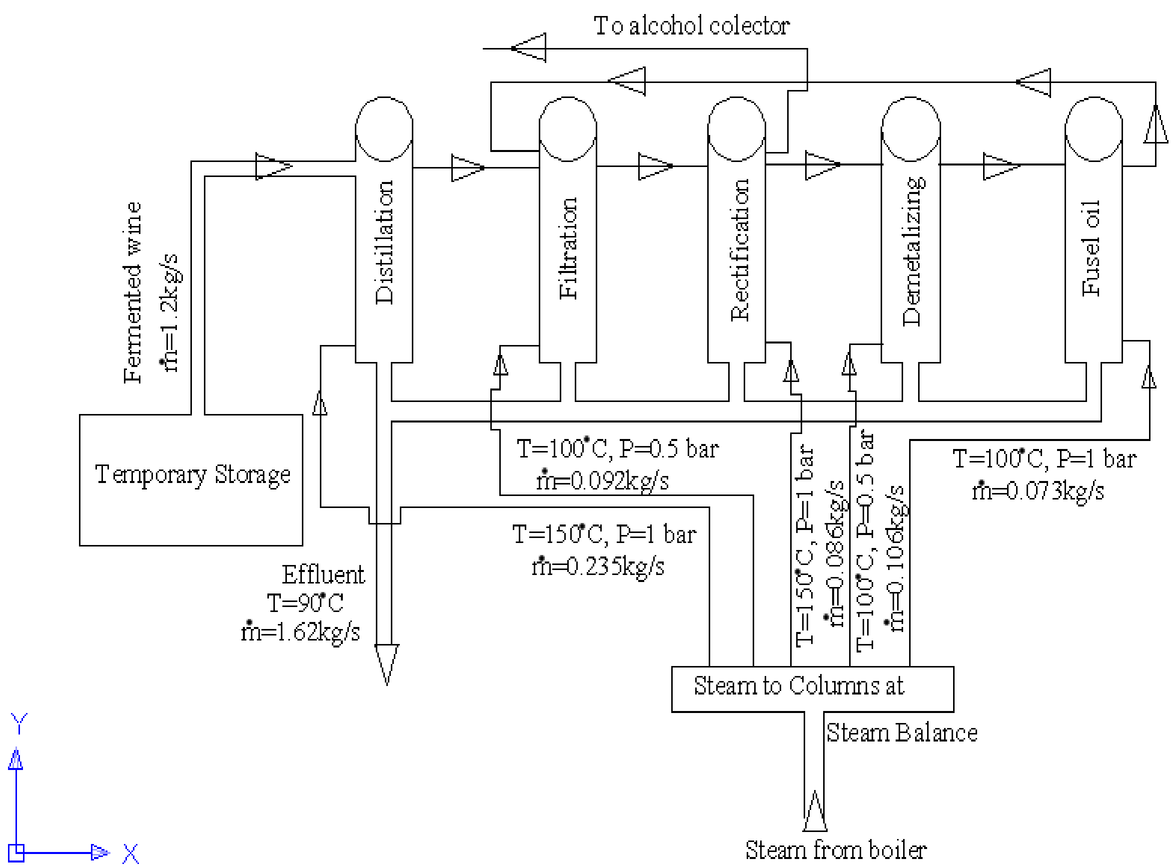


Figure 3.5 Flow Process of distillery columns

3.7.1 Distillation Column

This column takes $3000\frac{lit}{hr}$ of fermented wine in its upper portion and distils it using $0.455\frac{m^3}{s}@1bar\ and\ 150^O C$ of steam through the bottom of the columns. As primary stage of distillation taken place in this column and here it is exposed to organic minerals and acids easily. In addition calcium sulphate ($CaSo_4$) form a scale on the cups and plates, as result the process of removing the scale, exposes the column for damage untimely. The major task of the column are the following.

- 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 SO_2 (sulphur dioxide), Carbon dioxide (CO_2) and other solutions having lower boiling points from the bottom of the column.

3.7.2 Filter column

Similarly, this column distils $828\frac{lit}{hr}$ of 30-50% of alcohol received from distillation column by boiling with $0.314\frac{m^3}{s}@0.5bar\ and\ 100^O C$ steam coming form the bottom. In this column aldehyd and other undesirable solutions are removed as effluent and the distilled alcohol is transferred to the rectification column.

3.7.3 Rectification Column

The main task of this column is to produce pure alcohol. The distilled alcohol having 30-35 % alcohol content liquid is boiled by $0.167\frac{m^3}{s}@1bar\ and\ 150^O C$ steam coming from the bottom and is distilled at different stages. The internal temperature of the column is 80 ^{0}C. And 96.97 % pure alcohol is produced. From the top part of the column a pure alcohol having better quality will be produced, the rest of the alcohol is sent to demethylizing column (to purify alcohol form methane). In addition to this, from the lower part of the column a high boiling point concentrated oils is sent to fusel oil column. On the other side, liquid free of alcohol is removed by mixing it with water form the lower parts of the column.

3.7.4 Demethylizing column

This column distillates the alcohol by feeding pure alcohol (99% alcohol) which comes form the rectification column to the top half part using $0.362\frac{m^3}{s}@0.5bar\ and\ 100^O C$ steam from the lower part to heat the solution in order to evaporate high volatile impurities. Then pure alcohol will be distilled which will be taken to the bottom part of the column. Since this column is made of copper materials it plays a great role to remove bad odours (aromas) to yield a quality product. The output from this column returns to the filter column for further purification.

3.7.5 Fusel oil column

This column distils a solution directly coming from the demethylizing column. Impurities from the upper demethylizing column will be sent to the fusel oil and heated in the pre-heater. This column evaporates easily volatile impurities using $0.124\frac{m^3}{s}@1bar\ and\ 100^O C$ steam form the bottom. Water and undesirable oily solutions will be discharged to the lower part. The solution at the tope of the column will be returned to the filter column. Figure 3.6 represent the layout of the factory.

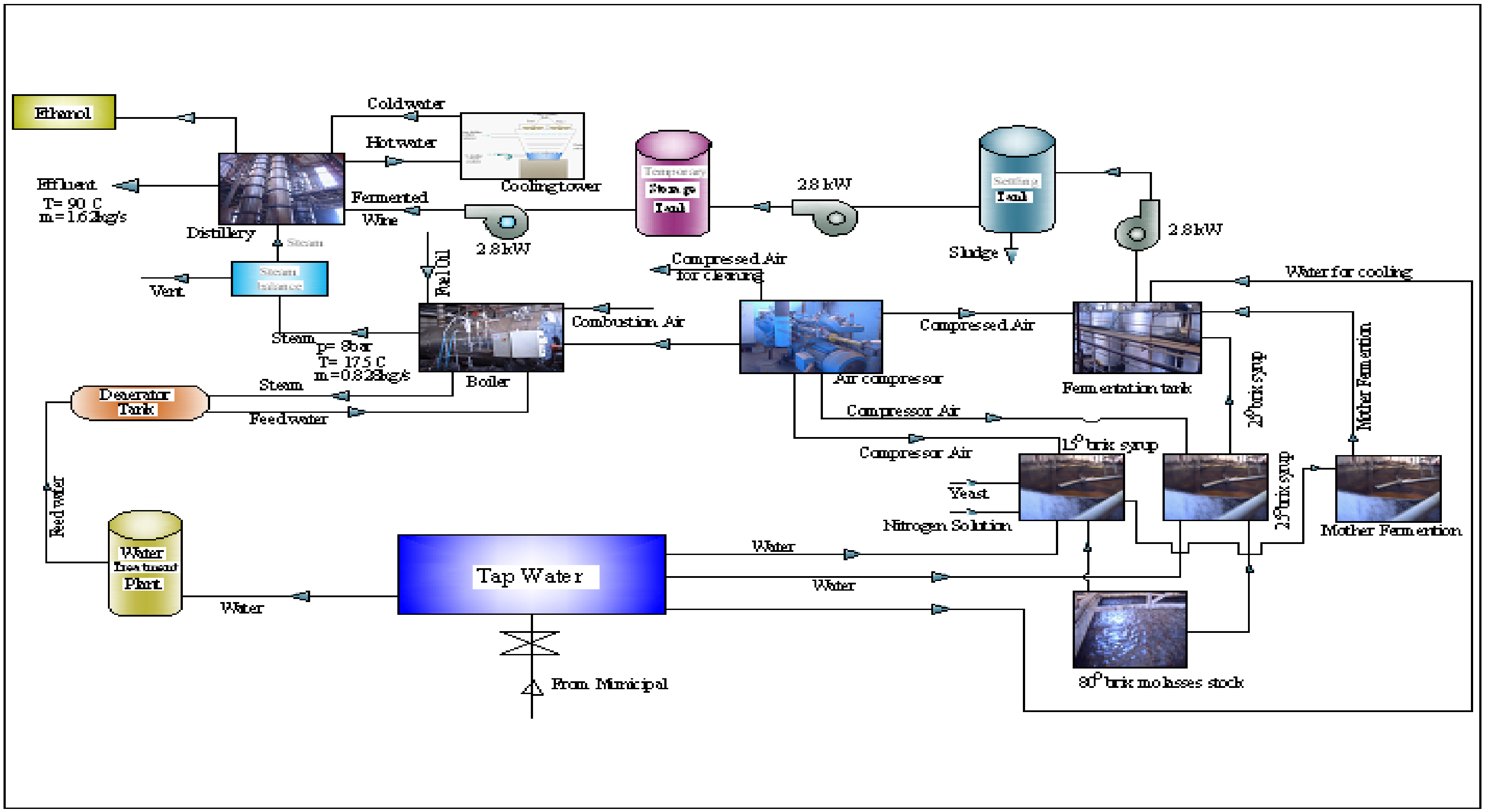


Fig 3.6 Factory Layout

CHAPTER 4

4 ENERGY BILL ANALYSIS

4.1 Introduction

The factory consumes both thermal energy and electric energy for ethanol production. The factory pays for both thermal energy and electric energy. For the 1998/99 (E.C) fiscal year the amount of energy bill paid by the factory were 7,584,424.52 Birr and 227,309.20 Birr for the furnace oil and electricity respectively.

The factory consumes both furnace oil and electricity in order to operate its major energy consuming systems. For example, electricity is consumed to operate motor, pumps and fans in the plant and also to operate different machineries in the plant machine shop. A small amount of electricity is also used for lighting. In addition to electricity, however, the core function of turning the fermented wine into final ethyl alcohol production in the distillery columns is accomplished through the consumption of large amounts of steam.

To analyze the factory's energy bill, the 12-month energy (furnace oil and electric), raw material and ethyl alcohol data are collected. In addition to this, energy intensity data of factories overseas (benchmark) are collected for comparison. These collected data are presented below.

4.2 Data Gathering

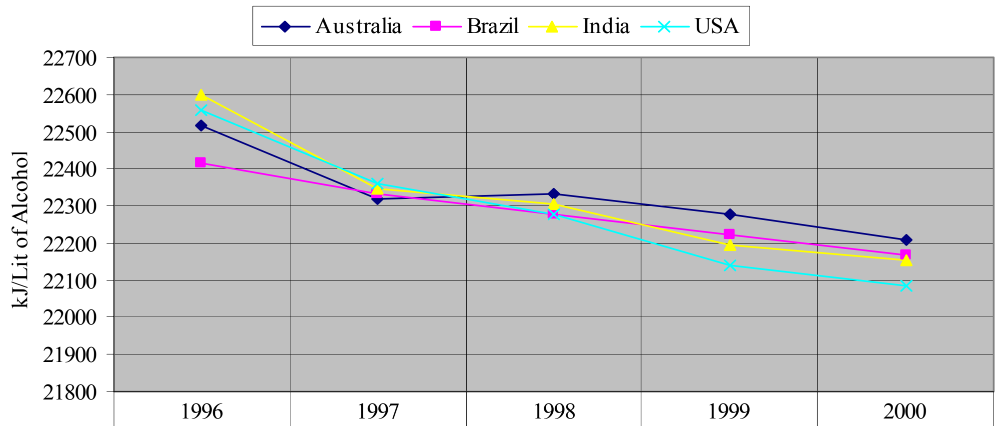
This section furnishes a 12-month data regarding the factory is consumption of furnace oil, electricity, raw materials (molasses) and the product (ethyl alcohol). It also reveals the energy intensities of factories overseas (benchmark) producing alcohol at greater amount and had so far good practices of alcohol production at efficient use of energy.

4.2.1 Factory Energy Consumption Data

In the past 12-monthes from March 1998 to Feb, 1999 E.C, furnace oil and electricity consumption data are collected from logbook and electricity bill respectively. In addition to energy consumption data, the corresponding raw material consumption and ethyl alcohol production data were collected from factory logbook. The data is presented in appendixes A.

4.2.2 Energy Consumption of Benchmark Countries

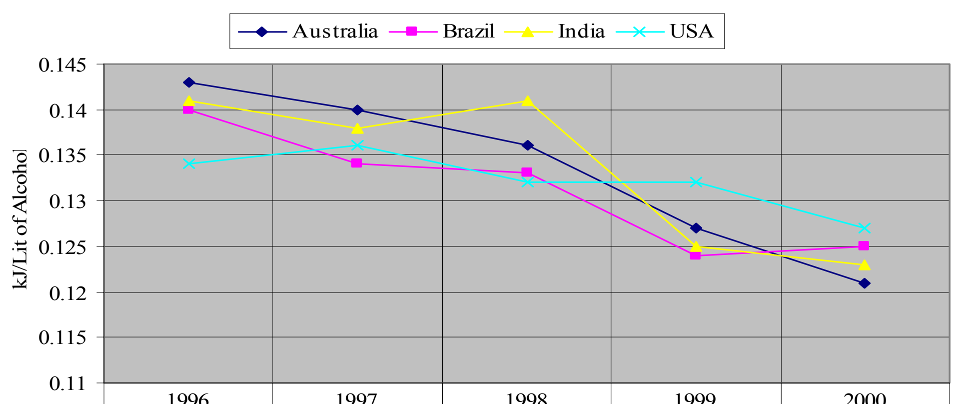
Figures 4.1 and Figure 4.2 provide the five years (1996-2000 G.C) fuel oil and electricity energy intensity consumption pattern of the benchmark countries: India, USA, Australia and Brazil. The value indicates in the figures are average value at national level.



	1996	1997	1998	1999	2000
Australia	22514.1	22319.2	22333.1	22277.4	22207.8
Brazil	22416.6	22333.1	22277.4	22221.7	22166
India	22597.6	22347	22305.3	22193.9	22152.1
USA	22555.9	22360.9	22277.4	22138.2	22082.4

Year(G.C)

Fig 4.1: Fuel oil energy intensity of the benchmark countries [23]



	1996	1997	1998	1999	2000
Australia	0.143	0.14	0.136	0.127	0.121
Brazil	0.14	0.134	0.133	0.124	0.125
India	0.141	0.138	0.141	0.125	0.123
USA	0.134	0.136	0.132	0.132	0.127

Year (G.C)

Fig 4.2: Electricity energy intensity of the benchmark countries [23]

4.3 Data Analysis

The collected data is processed into monthly factory paid for furnace oil and electricity consumption and monthly fuel and electricity energy intensity consumption patterns.

4.3.1 Monthly Energy Cost of the Factory

The cost of fuel oil is varying among geographical areas of the country. The prices are set by market condition (supply vs demand), but within any geographical area they are fairly consistent. Basically, the price is simply a flat change per litre, so the total cost is the number of litre used times the price per litre. The specific gravity and the gross calorific value (GCV) of furnace oil are 0.991 and $4.18X10^4$ kJ/kg respectively. The price is taken as 4.1653 Birr/litre according to Ethiopian petroleum agency price. Billing for electricity is varying according to voltage consumption and number of phases used in the factory. The factory use three phase and high voltage (15kV line), so according to Ethiopia Electric Power Corporation (EEPC) the tariff is high voltage tariff with flat multiplying factor of all consumed kWh is 0.34 Birr/kWh.

Monthly furnace oil and electricity cost are given by Equation 4.1 and 4.2 respectively.

$$MFC = 4.1653 \frac{Birr}{Litre} * monthly\ \ fuel\ used\ in\ liter \qquad \textbf{(4.1)}$$

where

MFC - Monthly fuel cost in [Birr/month]

$$MEC = 0.34 \frac{Birr}{kWh} * monthly\ electric\ used\ in\ kWh \qquad \textbf{(4.2)}$$

where

MEC - Monthly electricity cost

Using the data from appendix A and substituting in Equation (4.1) & (4.2) the monthly factory fuel and electricity cost is tabulated in Table 4.1. The following Table 4.1 and Figure. 4.3 provide the monthly energy cost for fuel and electricity consumption.

Table 4.1 Monthly Fuels and Electricity Cost at (MAF)

Billing Period (E.C)	Cost of Fuel (Birr)	Cost of Electricity (Birr)	Total cost (Birr)
Mar-98	643,663.81	19,599.51	633,327.31
Apr-98	646,054.69	19,622.55	637,848.87
May-98	637,315.89	19,640.40	642,115.33
Jun-98	592,209.86	17,757.31	611,616.63
Jul-98	591,968.27	17,749.06	608,900.93

Billing Period (E.C)	Cost of Fuel (Birr)	Cost of Electricity (Birr)	Total cost (Birr)
Aug-98	584,037.54	17,751.98	616,193.13
Sep-99	659,708.54	17,767.45	622,664.81
Oct-99	638,686.81	19,567.16	663,522.54
Nov-99	641,622.81	19,492.82	667,975.88
Des-99	651,019.73	19,498.89	672,467.98
Jan-99	649,711.82	19,427.11	676,898.90
Feb-99	648,424.75	19,434.96	681,371.94
Total	7,584,424.52	227,309.20	7,811,733.72

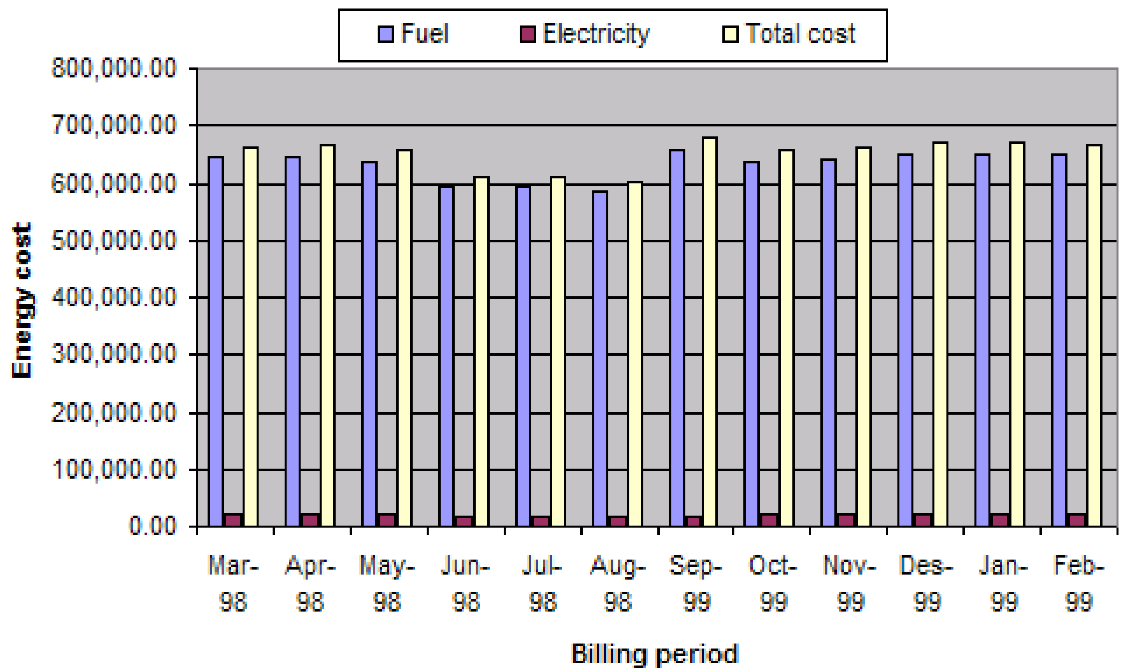


Figure 4.3 Monthly energy cost at (MAF)

4.3.2 Monthly Energy Intensity Consumption Pattern of the Factory

Monthly energy intensity consumption is defined as an average monthly energy needed to produce one litre of ethyl alcohol.

Monthly fuel and electricity energy intensity given by Equation 4.3 and 4.4, respectively

$$MFEI = \frac{GCV * \rho_{Fuel} * monthly\ \ fuel\ used(litre)}{monthly\ alcohol\ \ produced} \quad \textbf{(4.3)}$$

where

$MFEI -$ Monthly fuel energy intensity

$GCV -$ Gross calorific value of fuel in kJ/kg of fuel

$\rho_{Fuel} -$ Density of fuel kg/Lit

$$MEEI = \frac{monthly\ electricity\ used (kWh) * 3600 \sec}{monthly\ alcohol\ \ produced} \qquad \textbf{(4.4)}$$

where

$MEEL$ – Monthly electric energy intensity

Using data from appendix A and substituting in Equation (4.3) & (4.4), the monthly factory fuel energy intensity and electricity energy intensity is tabulated in table 4.2. The following Table 4.3 and Figure. 4.4 & 4.5 provide monthly fuel and electricity energy intensity.

Table 4.2 Monthly Energy Intensity of Fuel and Electricity

Billing Period (E.C)	Energy intensity of Fuel (kJ/litre of alcohol)	Energy intensity of Electricity (kJ/litre of alcohol)
Mar-98	26,718.35	866.2
Apr-98	26,925.45	870.7
May-98	26,676.93	875.3
Jun-98	29,742.28	949.5
Jul-98	29,907.98	954.7
Aug-98	28,996.66	944.6
Sep-99	27,753.95	939.2
Oct-99	27,008.32	876.4
Nov-99	27,132.58	877.6
Des-99	27,671.09	882.4
Jan-99	27,753.95	883.5
Feb-99	27,836.79	888.3

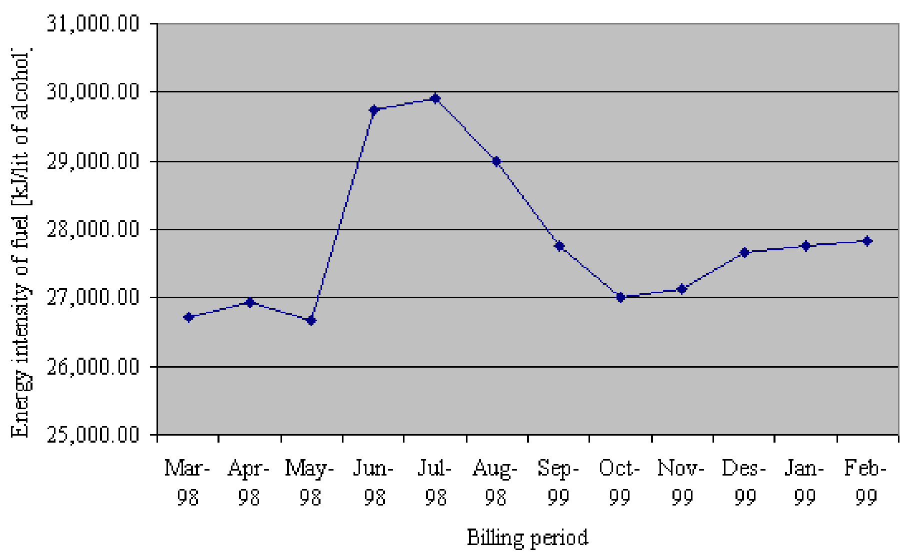


Figure 4.4 Factory Fuel Energy Intensity

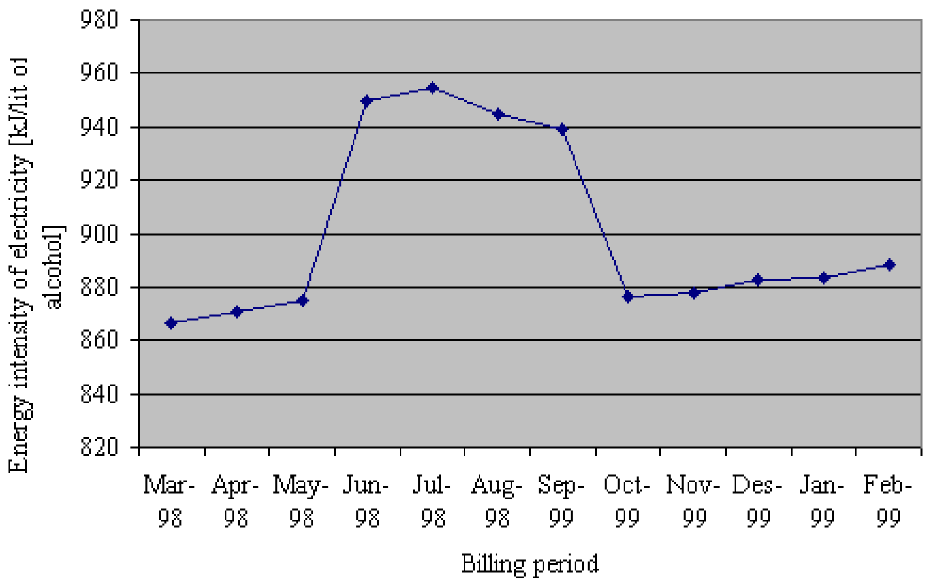


Fig 4.5 Energy intensity of electricity at (MAF)

4.4 Analysis of the Energy Utilization of the factory

As is clearly seen in Figure 4.4 and Figure 4.5 the energy utilization pattern of the factory considerably varies over the whole fiscal year, 1998/99 E.C. Both fuel and electric energy intensity during the months of June to September appear to increase significantly as compared to other months. For instance the energy intensity consumption of the month June is greater than the month of March by 3,023.93kJ/litre and 83.3kJ/litre for fuel and electric energy intensity respectively. The reason for increasing energy intensity during the months of June to September is idle running time for energy consuming machines due to shortage of molasses (raw material), the production of ethyl alcohol is decreased. And also Figure 4.4 clearly show that the fuel energy intensity consumption is slightly varies from month to month. These variation indicate that the energy efficiency of the boiler with time has decreased. Thus the boiler is one of the main energy consuming systems of the factory that must be investigated in thoroughly.

4.5 Energy Intensity Comparison of Factory with Benchmark

The comparison is made between energy intensity of Mekanissa Alcohol Factory (MAF) and the benchmark. From the analysis of the energy intensity of the MAF it can be seen that there is a significant difference between the energy intensity of the MAF as compared to the benchmark.

The twelve-months fuel energy intensity of MAF ranges from 26,676.93 – 29,907.98 kJ/Lit of alcohol with monthly average energy intensity of 28,292.45 kJ/Lit of alcohol. The energy intensity of benchmark, for example Brazil shown in Figure 4.1 gives monthly average energy intensity of 22,298.55 kJ/Lit of alcohol. Hence a difference of 5996.9kJ/Lit exists between the average practice of the benchmark and what exists at MAF.

The electricity energy intensity of MAF in the twelve-months, ranges between 0.241 to 0.265kWh/Lit of alcohol with an average intensity of 0.25kWh/Lit of alcohol. The energy intensity of the benchmark, for example Australia showed in Figure 4.2 gives an average energy intensity of 0.132kWh/Lit of alcohol. Hence a difference of 0.12kWh/Lit exists between the average practice of a benchmark country and what exists at MAF.

4.5.1 MAF Cost Comparison with Benchmark

The results presented show difference in energy intensity of MAF with the benchmark and it is discussed below.

Important Data

1. MAF Production in 98/99 E.C = 2,679,964.6Lit of alcohol [Table4.1]
2. Cost of fuel oil = 4.1653birr / lit
3. Cost of electricity = 0.34birr /kWh flat rate
4. Specific heat of fuel oil = 41,423.8 kJ/Lit
5. Difference in fuel energy intensity = 5996.9kJ/Lit of alcohol
6. Difference in electricity energy intensity = 0.12kWh/ Lit of alcohol

Difference in annual energy cost due to lower efficiency use of fuel and electricity are obtained using Equation (4.5) and equation (4.6) for fuel and electricity, respectively.

$$AC_{Fuel} = \frac{DEI_{Fuel} * FAPC * CF}{GCV} \qquad \textbf{(4.5)}$$

where

AC_{Fuel} – Difference in annual cost due to lower fuel energy intensity

DEI_{Fuel} – Difference of fuel energy intensity

$FAPC$ – Factory annual production capacity

CF – Cost of fuel [Birr]

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

Substituting the above values from the data in Equation (4.5) annual energy cost due to lower efficiency of fuel of the factory is given by:

$$AC_{Fuel} = \frac{5996.9\frac{kJ}{Lit_{Alcohol}} * 2{,}679{,}964.6\frac{Lit_{Alcohol}}{Year} * 4.1653\frac{Birr}{Lit_{Fuel}}}{41{,}423.8\frac{kJ}{Lit_{Fuel}}}$$

= **<u>1,616,040.40 Birr/ year</u>**

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

$$AC_{Ele} = DEI_{Ele} * FAPC * CE \qquad \textbf{(4.6)}$$

where

$AC_{Ele} -$ Difference in annual cost due to lower electricity energy intensity

$DEI_{Ele} -$ Difference of electricity energy intensity

$FAPC -$ Factory annual production capacity

$CE -$ Cost of electricity in Birr

Substituting the above value from the data in Equation (4.5) annual energy cost due to lower electricity energy intensity of the factory is given by

$$AC_{Ele} = 0.12\frac{kWh}{Lit_{Alcohol}} * 2{,}679{,}964.6\frac{Lit_{Alcohol}}{Year} * 0.34\frac{Birr}{kWh}$$

= **<u>109,342.56Birr/ year</u>**

Therefore,

Total Annual cost due to low energy utilization of the factory is given by equation (4.7).

$$AEC = AC_{Fuel} + AC_{Ele} \qquad \textbf{(4.7)}$$

Substituting Equation (4.5) and (4.6) in Equation (4.7), the total annual cost due to lower efficiency of energy utilization of the factory

= **<u>1,725,382.96Birr/ year</u>**

4.6 Concluding Remark on the Energy Intensity Comparison

Based on the above analysis, the MAF energy utilization system is seen to be in efficient and more costly as compared to the benchmark. This is mainly due to energy mismanagement and lack of attention to energy wastage during low production season. The losses incurred by the factory greatly reduce its profits. Thus the factory must conduct energy audit on its major energy systems.

CHAPTER 5

5 PRELIMINARY ENERGY AUDIT OF THE FACTORY

5.1 Introduction

As per the explanation given in Chapter 1, section 1.4.2.1, the preliminary energy audit of the factory is performed through inspection of the nine general energy systems: the building envelop, boiler and steam distribution systems, the heating ventilating and air conditioning systems (HVAC), the electric supply systems, the lighting systems, hot water distribution systems, the compressed air distribution systems, the motor and production process systems using visual inspection, common sense and interview with factory workers in order to identify energy conservation opportunities (ECO_S) and identify the major energy systems of the factory to perform the detail energy audit of the major systems. From the above nine general energy systems the following systems are selected to be discussed.

5.2 Inspection of the Boiler and Steam Distribution Systems

The boiler used in the factory is manufactured by an Italian company, with two- pass fire tube design. The systems includes in the boiler are: feed water system, steam system and fuel system. In addition to these main systems, the boiler has deaerator and none functional water treatment plant.

The feed water system provides water to the boiler and regulates it automatically to produce the specified capacity of steam in the boiler. There is no condensate return because the steam is used as feed steam. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the different points of use. Throughout the system, steam pressure is regulated using manual valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the heat. The boiler uses furnace oil.

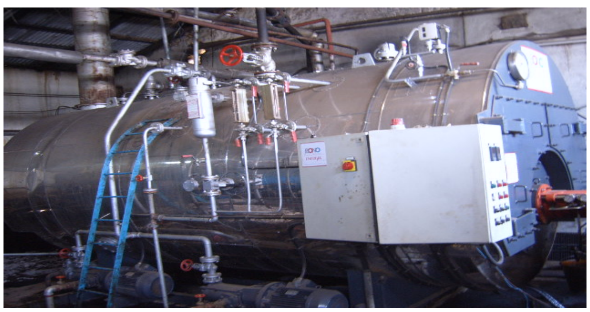


Fig 5.1 Factory boiler

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

5.2.1 List of ECO$_S$ Identified

The various energy efficiency opportunities in boiler and steam distribution line systems can be related to combustion, heat transfer, avoidable losses, water quality and blowdown. These are inspected and the following list of ECO$_S$ are discovered.

1) No periodic soot blowing of the boiler is done,
2) No periodic scale removing of the boiler waterside,
3) Steam traps are not checked for proper functioning regularly,
4) The boiler is very dirty,
5) Some length of live steam pipes to distillery columns are bare,
6) The boiler is without an economizer.
7) The water treatment plant is not functional due to the failure of some component of the plant.
8) The carbon dioxide content of the flue gases of the boiler is much more below the recommended value, which affects the efficiency of the boiler negatively.
9) The steam produced is greater than the steam demand, therefore the boiler is oversized

The ECO$_S$ listed from number 1-5 above are simple to be implemented with the routine maintenance program of the factory with no or low cost. But the ECO$_S$ listed from number 6-9 need further data collection and entails conducting detail energy audit of the boiler.

5.3 Inspection of the Compressed Air Distribution System

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

Fig 5.2 Factory Air Compressor

The factory is air compressor and compressed air distribution systems are used to mix water with molasses in the fermentation process, operate pneumatic valve and dust remover. The compressed air distribution system has no leak and the compressor is placed properly but mostly the dust collector valve is resided open for long time after completing its task.

5.3.1 Lists of ECO_S Identified

There is no systematic control of compressed air distribution valves.

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

5.4 Inspection of the Motor Systems

There are over 12 three phase motors in the factory floor in order to move pumps, fans and air compressor that operate in the range of 720 hr to 7200 hr per a year. Inspection of the motor system is conducted using visual inspection common sense and interview made with electrical maintenance personnel and revealed the following energy conservation opportunities.

5.4.1 Lists of ECO_S Identified

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

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

The ECO_S listed as number 1 above are simple to be implementing with the routine maintenance program of the factory with no cost. But the ECO_S listed as number 2 and 3 need further data collection and entails conducting detail energy audit of the motors with their prime movers.

5.5 Inspection of the Production Process

The manufacturing systems of the factory intensively utilized thermal and electric energy. All the thermal energy is consumed by the distillation process. The electric energy mainly drives pumps, air compressor and fans.

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.

Fig 5.3 Factory Distillery Columns

Inspection of manufacturing system means inspection of distillation system because it consumes all thermal energy produced by the boiler. Hence inspection of the motor system is conducted using visual inspection common sense and interview made with factory personnel and revealed the following energy conservation opportunities.

5.5.1 Lists of ECO_S Identified

The distillation system of the factory was assessed for potential ECO_S and the following were obtained.

1. Frequent production interruption due to scale developed inside distillation column.
2. For long time the pressure sensing and flow rate measuring instruments of the distillery system were not calibrated,
3. The trays and cups of the columns are old and worn out,
4. Large quantity of steam is vent just before entering distillery columns,
5. Large quantity of effluent at a temperature of 90 ^{O}C is channelled to the river.

ECO_S 1-3 from the above lists of technically feasible ECO_S are low cost or no cost energy conservation opportunities sorts that can be handled with the routine maintenance and job of the factory. ECO_S number 4 and 5 require further data collection on vent steam, effluent and fermented wine and it will be appropriate to discuss it on detail energy audit.

5.6 Identification of the Major Energy Systems of the Factory

As is clearly discussed in the preceding chapters there are so many equipments that are engaged in the production of alcohol having direct relation with energy consumption or development in the factory. From production process, the preliminary audit result and, interview made with factory workers the major energy systems of the factory are found to be:

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

Moreover, of the total energy production from furnace oil, almost all goes to distillery. And the total energy supplied from electric power, almost 90%, goes to motors. 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 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 performed through assessment of their energy performance according to the following categories in a separate chapter.

- Thermal energy audit of:
    - Boiler
    - Distillery
- Electric energy audit of:
    - Motors and their prime movers

CHAPTER 6

6 DETAILED ENERGY AUDIT OF THE BOILER

6.1 Introduction

The type of boiler used by the factory is SM/FB 300/15/N/2P-R/ELLO fire tube steam-generator and it is manufactured by an Italian company in 2000 G.C. The designed capacity of the boiler is 3 ton/hr @ a temperature of 175 ^{O}C and a pressure of 8 bar. Its main function is to supply superheated steam to the distillery columns. In order to perform the energy accountings, energy balances and determine the efficiency of the boiler, the following data/measurements are required.

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

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

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

6.2 Data Collection for Conducting Detail Energy Audit of the Boiler

Inspection of the boiler and steam distribution system is conducted using portable combustion analyzer, infrared and dual K contact thermometer, tape rule, ultrasonic flow meter and visual inspection.

6.2.1 Flue Gas Analysis

Portable Combustion Analyzer (PCA) is used to analyze combustion routinely for tune-ups, maintenance and emissions monitoring. These instruments are extractive. They remove a sample from the stack or flue with a vacuum pump and then analyze the sample using electrochemical gas sensors. Thermocouples are used for stack and combustion air temperature measurements.

A pressure transducer is used for the draft pressure measurement. An in-built computer performs the common combustion calculations, and shows the results of constituents of gases and draft pressure. These data are presented in Table 6.1.

Table 6-1 Measured Flue Gas Data

	Reading	Data collection methods
O_2 in flue gas [%]	10.6	Measured
q_A [%]	14.5	Measured
Stack temperature [^{0}C]	224	Measured
Ambient temperature [^{0}C]	25	Measured
CO_2 [%]	7.8	Measured
CO [ppm]	10	Measured
Draft [WC]	0.39	Measured
Free stream air composition		
Nitrogen 79%	Oxygen 21%	

6.2.2 Boiler Surface Loss Analysis

To estimate the energy lost from the boiler surfaces, surface temperatures of the boiler that are exposed to the ambient are measured at different location using an infrared and dual K contact thermometer. The boiler is cylindrical in shape and surfaces that are exposed to the ambient are: the cylindrical surface, the front and back surfaces. In addition to boiler surface temperatures, blowdown, feed water and vent steam temperatures are measured. The averages of these measurements are listed in Table 6.2.

Table 6-2 Measured boiler temperature

No	Measured side	Surface temp [^{0}C]	Ambient temp [^{0}C]
1	Front Surface	107.7	32
2	Cylindrical Surface	31	26
3	Back	42	27.5
4	Blowdown Temperature = 110 ^{0}C		
5	Feed Water Temperature = 80 ^{0}C		
6	Vent Steam Temperature = 125 ^{0}C		
7	Fuel pre-heating Temperature = 110 ^{0}C		
8	Datum (ambient) Temperature =25 ^{0}C		
9	Steam produced at a temp.175 ^{0}C & pressure of 8 bar		

6.2.3 Boiler Dimensions Analysis

A Vernier's calliper was used to measure the internal pipe diameters of feed water pipe, blowdown pipe, steam vent pipe and fuel oil pipe. The diameters of each pipe were the same and are 0.0508m. An Ordinary tape rule was used to measure the dimensions of the boiler. The boiler is cylindrical in shape and it has three surfaces exposed to the ambient air. The surface areas of the boiler exposed to the ambient are the following:

$$A_{cylindrical} = \pi DL = \pi 1.75m \times 4.5m = 24.74m^2$$

$$A_{front} = \frac{\pi D^2}{4} = \frac{\pi (1.75)^2}{4} = 2.41m^2$$

$$A_{back} = \frac{\pi D^2}{4} = \frac{\pi (1.75)^2}{4} = 2.41m^2$$

6.2.4 Boiler Fluids Flow Velocity

To facilitate the estimation of fluid flow through a pipe, ultra sonic flow meter is used. Using this meter the following flow velocities were measured: fuel flow velocity, blowdown flow velocity, and feed water flow velocity and are presented in Table 6.3.

Table 6-3 Flow Velocities

Item	Flow Type	Measured Velocity [m/s]					
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Feed Water	Continuous	0.6406	0.6403	0.6405	0.6402	0.6403	0.6403
Fuel Oil	Continuous	0.0421	0.04207	0.0422	0.04206	0.0421	0.0421
Vent Steam	Continuous	0.108	0.105	0.102	0.106	0.104	0.105
Blowdown	Intermittent	0.115	0.113	0.111	0.111	0.112	0.112

6.3 Pre-Audit Energy and Mass Balance Analysis

In order to perform the detailed energy audit of the boiler the following pre-audit input-output energy and mass balance analysis are compulsory.

- Heating value of furnace oil,
- furnace oil combustion, and
- mass flow rate of fuel, feed water, blowdown and steam

6.3.1 Heating Value of Furnace Oil

The factory uses furnace oil as fuel source to generate steam. The calorific values of furnace oil are important to determine the input energy into 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 will as chemical composition. According to reference [4], the chemical and physical composition and gross calorific values (GCV) of furnace oil are as shown in Table 6.4.

Table 6-4Composition of Furnace oil and Ultimate Analysis

Composition of Furnace oil	Symbol	Ultimate Analysis in %
Carbon	C	84
Hydrogen	H	12
Oxygen	O_2	1.5
Sulphar	S	1.5
Nitrogen	N_2	0.5
Moisture	M	0.5
Gross Calorific Value = 41,800kJ/kg		

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 (6.1) the net calorific value of furnace oil can be estimated.

$$NCV = GCV - \left(M_{H_2O}\right) \times h_{fg} \quad \textbf{(6.1)}$$

where

h_{fg} - Enthalpy of vaporization of water = 2441.12kJ/kg

$\left(M_{H_2O}\right)$ - Mass of water vapour in the flue gas

$$\left(M_{H_2O}\right) = 9 \text{ H } (1\text{-}\%\text{M}) + \%\text{M} \quad \textbf{(6.2)}$$

H mass of percent of hydrogen in the furnace oil

From Table 6.1 the percent of hydrogen in furnace oil is 12%. Hence Equation (6.2) becomes:

$$\left(M_{H_2O}\right) = 9\text{x } 0.12(1-0.5) + 0.5 = 1.04 \quad \textbf{(6.3)}$$

Substituting the values of Equation (6.3), GCV and h_{fg} NCV in (6.1) becomes:

NCV = 41,800kJ/kg - (1.04 x 2441.12kJ/kg)

= 39261.235kJ/kg

6.3.2 Analysis of furnace oil combustion

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

- Analysis of the constituents of combustion air
- Air-fuel ratio of furnace oil burning
- Mass analysis of dry flue gases

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 [Table 6.1]. The air used for combustion is composed of moisture, oxygen and nitrogen at standard condition 27^{O}C and P_a=1atm. The average relative humidity of the air used for combustion is $\phi = 53.25\%$ [20]. To perform molar analysis of the combustion air constituents easily, the absolute humidity and mass fraction of air constituents relative to oxygen must be found.

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 26.56^{O}C. The humidity factor of the air is given by

$$\text{Humidity factor } (\gamma_A) = 0.622 \frac{P_v}{P_o} \qquad \textbf{(6.4)}$$

where

$$P_o = P_a - P_v$$

But the value of the partial pressure of the water,

$P_v = \phi P_{sat@27^O C} = 53.25\% P_{sat}$ From steam table at 27^{O}C the value of the saturation pressure, P_{sat}= 3.634kPa hence $P_v = 53.25\% \times 3.634 kPa = 1.935105 kPa$ and P_o = 99.38 kPa

Therefore, humidity factor (γ_A) = 0.622 *(1.935105 kPa /99.38 kPa) =0.01211 kg of H_2O/ 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 indispensable 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 6.5

Table 6-5 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 $\frac{x*M}{28.678}$	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_2O	-	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 of Furnace oil Burning

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

a) Theoretical Air-Fuel Ratio (TA)

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 [4]. The percentage of fuel constituents is presented in Table 6.4

TA = [(11.6 x C) + {34.8 x (H_2 -O_2/8)} + (4.35 x S)]/100 kg/kg of fuel oil

= [(11.6 x 84) + {34.8 x (11.8)} + (4.35 x 1.5)]/100 kg/kg of fuel oil

= 13.92 kg of air/kg of oil **(6.5)**

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

The actual mass of air used during burning of one kg of fuel in boiler furnace can be easily found from equation (6.6).

Actual mass of air supplied (AA) = $\left[1+\frac{EA}{100}\right]\times TheoriticalAir$ (TA) **(6.6)**

where

EA - excess air supplied

TA - theoretical amount of air fuel ratio

But the excess air supplied can be obtained by using equation (6.7).

Excess Air Supplied (EA)

The excess air supplied to the boiler/furnace may be computed using the percentage of oxygen present listed in table 6.1 and using formula (6.7).

$$\text{Excess air supplied (EA)} = \frac{O_2\%}{21\% - O_2\%} \times 100 \qquad \textbf{(6.7)}$$

$\%O_2$ measured in flue gas = 10.6 % and substitute in (6.7) the excess air is:

$$EA = \frac{10.6\%}{21\% - 10.6\%}$$

$$= 102\ \% \qquad \textbf{(6.8)}$$

Substitute (6.8) & (6.5) in (6.6) the actual air supplied is:

AA = [1 + 102/100] x [13.92]

= 28.12 kg of air / kg of fuel

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

Table 6-6 Molecular weight of the constituents of the fuel

Element or Compound	C	O_2	H_2	S	N_2	CO_2	SO_2	H_2O
Molecular Weight	12	32	2	32	28	44	64	18

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

1kg of furnace oil + Dry air $\rightarrow$ $CO_2 + H_2O + SO_2 + N_2$

Mathematically:

$$C + O_2 \rightarrow CO_2$$

$$H2 + \frac{1}{2}O_2 \rightarrow H_2O$$

$$S + O_2 + \rightarrow SO_2$$

Constituents of fuel

$$C + O_2 \rightarrow CO_2$$

$$12 + 32 \rightarrow 44$$

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

$$(0.84)C + (0.84 \times 2.67)O_2 \rightarrow 3.083CO_2$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$4 + 32 \rightarrow 36$$

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 32/4 kg i.e.8 kg of O_2

$$0.12H_2 + (0.12 \times 8)O_2 \rightarrow 1.08H_2O$$

$$S + O_2 \rightarrow SO_2$$

$$32 + 32 \rightarrow 64$$

32 kg of S requires 32 kg of O_2 to form 64 kg of SO_2, therefore 1 kg of S requires 32/32 kg i.e. 1 kg of oxygen

$$0.015S + (0.015 \times 1)O_2 \rightarrow 0.03SO_2$$

Excess air = Actual air supplied - Theoretical air required

= 28.12 kg - 13.92 kg

= 14.2 kg of air

Excess O_2 = 14.2kg x 0.23(by mass) = 3.3kg

Excess N_2 = 14.2kg x 0.77(by mass) =11kg

The final constitution of flue gas with 102 % excess air for every 1 kg fuel is the summation of the constitution list below.

$CO_2 = 3.083kg$ /kg of fuel

$H_2O = 1.08kg$ / kg of fuel

$SO_2 = 0.03kg$ / kg of fuel

$O_2 = 3.3$ kg/ kg of fuel

$N_2 = 11$ kg + 10.72 kg = 21.72 kg/ kg of fuel

Therefore, total mass of flue gas (m) = 29.4 kg flue/ kg fuel **(6.9)**

Multiplying (6.9) with mass flow rate of furnace oil (6.3) gives the mass flow rate of flue gases ($\dot{m}_{flue}$)

$$\dot{m}_{flue} = 29.4 \frac{kg_{flue}}{kg_{fuel}} \times 0.0635 \frac{kg_{fuel}}{\sec}$$

$$= 1.87 \frac{kg_{flue}}{\sec} \qquad \textbf{(6.10)}$$

6.3.3 Combustion Temperature Estimation of the Furnace

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 [7]. For 0.5% moisture content of furnace oil, the furnace temperature at 102% excess air is 605.3 ^{O}C.

6.3.4 Specific Heat of Dry Flue Gases

For furnace oil, the specific heat of dry flue gas is given by [7]

$$C_{P_{fg}} = (0.3 + 0.000038 T_{furnace}) kcal / kg\,^{O}C$$

where

$T_{furnace}$ - Furnace temperature

Substituting the value of furnace temperature the specific heat of the flue gas is given by

$$C_{P_{fg}} = (0.3 + 0.000038 \times 605.3) kcal / kg\,^{O}C$$

$$= 0.323 kcal / kg\,^{O}C = 1.35 kJ / kg\,^{O}C$$

6.3.5 Analysis of Mass Flow Rate of the Boiler

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

6.3.5.1 Analysis 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 determine the input energy in to the boiler. 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 (6.11) and (6.12) respectively.

$$\dot{m}_f = V_f \times A_f \times \rho_f \quad \textbf{(6.11)}$$

but

$$A_f = \frac{\pi D^2}{4} \quad \textbf{(6.12)}$$

where

A_f - Area of fuel flow pipe

V_f - Velocity of fuel flow =0.0421$^{m}/_{s}$

ρ_f - Density of fuel = 991 $\frac{kg}{m^3}$

D - Diameter of pipe = 0.0508 m

Substituting the above data in Equation (6.12) the area of fuel flow pipe can be determined as:

$$A_f = \frac{\pi D^2}{4} = (3.14 * (0.0508)^2) / 4 = 0.001521\text{m}^2$$

Substituting pipe area and the above data in Equation (6.11) the mass flow rate of furnace oil is:

$$\dot{m}_f = V_f \times A_f \times \rho_f = 0.0421\,^{m}/_{s} * 0.001521\text{m}^2 * 991\frac{kg}{m^3} = 0.0635\frac{kg}{s} \quad \textbf{(6.13)}$$

6.3.5.2 Analysis of Mass Flow Rate of Feed Water

Feed water is one of the major input sources of steam production. The mass flow rate of feed water is important to determine the input energy in to the boiler. The mass flow rate can be calculated by directly multiplying of feed water flow velocity, area of the pipe, feed water flow and the density of feed water. The measured velocity, pipe diameter and density are presented in Table 6.3. The mass flow rate of feed water and pipe flow area can be obtained using equation (6.14) and (6.15) respectively.

$$\dot{m}_w = V_w \times A_w \times \rho_w \quad \textbf{(6.14)}$$

$$A_w = \frac{\pi D^2}{4} \quad \textbf{(6.15)}$$

where

V_w - Velocity of feed water flow =0.6403 m/s

ρ_w - Density of water = $1000\,\frac{kg}{m^3}$

A_w - Water flow area = $\frac{\pi D^2}{4} = \frac{\pi(0.0508m)^2}{4} = 0.001521m^2$

Substituting the value of the above data in Equation (6.14) the daily mass flow rate of feed water becomes:

$$\dot{m}_w = 0.6403\,m/s * 0.001521\text{m}^2 * 1000\,\frac{kg}{m^3}$$

$$\dot{m}_w = 84{,}153.6 \text{ kg/day} \quad \textbf{(6.16)}$$

6.3.5.3 Analysis 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 lowest point of the boiler shell. Blowdown is done to reduce total dissolved solids (TDS). The takes place by opening a 0.0508m diameter line for twice a shift for 5 minutes. The measured velocity, pipe diameter and density are presented in Table 6.3. The mass flow rate of blowdown and pipe flow area can be obtained using equation (6.17) and (6.18) respectively.

$$\dot{m}_b = V_b \times A_b \times \rho_b \quad \textbf{(6.17)}$$

$$A_b = \frac{\pi D^2}{4} \quad \textbf{(6.18)}$$

t_{day}= 1800sec

where

V_b - Velocity of blowdown flow = 0.112 m/s

ρ_b - Density of blowdown = $951\,\frac{kg}{m^3}$

D - Diameter of the pipe = 0.0508m

t_{day} –Daily total time of blowdown

Substituting the value of the diameter in Equation (6.18) the flow area is:

$$A_b = \frac{\pi D^2}{4} = \frac{\pi\left(0.0508m\right)^2}{4} = 0.001521m^2 \qquad \textbf{(6.19)}$$

Substituting Equation (6.19) and the above data in Equation (6.17) the daily mass flow rate of the blowdown is obtained.

$$\dot{m}_b = 0.112 \, m/s * 0.001521\text{m}^2 * 951 \frac{kg}{m^3}$$

$$\dot{m}_b = 291.6 \text{ kg/day} \qquad \textbf{(6.20)}$$

6.3.5.4 Analysis of Mass Flow Rate of Steam

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

$$\dot{m}_S = \dot{m}_w - \dot{m}_b \qquad \textbf{(6.21)}$$

where

$\dot{m}_w$ - Mass flow rate of feed water = 84,153.6 kg / day

$\dot{m}_b$ - Mass flow rate of blowdown = 291.6 kg / day

$\dot{m}_S$ - Mass flow rate of steam

Substituting the above data in (6.21) the mass flow rate of steam is given:

$$\dot{m}_S = \dot{m}_w - \dot{m}_b$$

$$= (84{,}153.6 - 291.6) \text{ kg / day} = 83{,}862 \text{ kg / day} \qquad \textbf{(6.22)}$$

6.3.5.5 Analysis of Mass Flow Rate of Vent Steam

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

$$\dot{m}_v = A_v \times V_v \times \rho_v \qquad \textbf{(6.23)}$$

where

ρ_v -density of vent steam = $\frac{1}{v_v} = \frac{1}{0.001065\frac{m^3}{kg}} = 938.97\frac{kg}{m^3}$

A_v -area of vent steam flow pipe $= 0.001521 m^2$

V_v -Velocity of vent steam $= 0.105\frac{m}{s}$ [Table 6.3]

Substituting the above data in Equation (6.23) the mass flow rate of vent steam is given by

$$\dot{m}_v = 0.001521 m^2 \times 0.105\frac{m}{s} \times 938.97\frac{kg}{m^3}$$

$$\dot{m}_v = 0.15\frac{kg}{s}$$

6.4 Energy Analysis of the Boiler

To perform the thermal energy audit of the boiler and thereby obtain the first law combustion and boiler efficiency, thermal energy analysis of the boiler must be conducted. The energy analysis is done based on the energy input and output of the boiler. All the input-output energy of the boiler are shown in Figure 6.1.

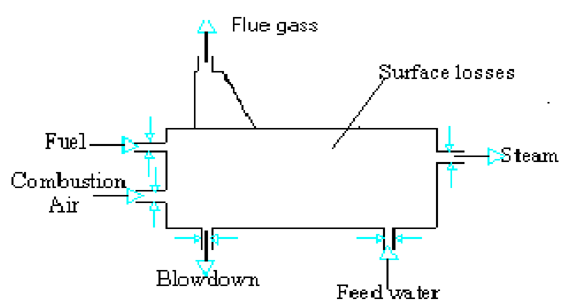


Fig 6.1 Input-Output of the Boiler

6.4.1 Analysis of the Input Energy in the Boiler

As illustrated in Figure.6.1 furnace oil, furnace oil due to its pre-heating, combustion air and feed water are the input energy of the boiler. Each input energy source of the boiler is discussed below.

i. Furnace 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 of Furnace Oil

The chemical energy of the furnace oil is quantified using its heating value. To calculate the energy efficiency of the boiler on GCV, the chemical energy of the furnace oil must be found. The chemical energy of the furnace oil is obtained by multiplying GCV of the fuel with the mass flow rate of the fuel. Table 6.1 and equation (6.13) present the GCV and mass flow rate of the furnace oil respectively; hence, the chemical energy of the fuel can be obtained by using Equation (6.24).

$$Q_f = \dot{m}_f (GCV) \tag{6.24}$$

where

Q_f - Chemical energy of the fuel

$\dot{m}_f$ - Mass flow rate of the fuel = $0.0635\frac{kg}{s}$ (6.13)

GCV - Gross calorific value of the fuel = $41,800\frac{kJ}{kg}$ [Table 6.4]

Substituting the above data in Equation (6.23) the chemical energy of the fuel is

$$Q_f = \dot{m}_f (GCV)$$

$$= 0.0635\frac{kg}{s} \text{ x } 41,800\frac{kJ}{kg}$$

$$= Q_f = \underline{\mathbf{2654.3kW}}$$

b. Energy Due To Fuel Pre-Heating

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

$$[Furnace\ Oil]_{25^oC} \rightarrow [Furnace\ Oil]_{110^oC}$$

The energy due to pre-heating temperature can be obtained using the following equation (6.25)

$$Q_{f1} = \dot{m}_f \times C_f \times (T_f - T_a) \tag{6.25}$$

where

Q_{f1} = Energy content due to fuel pre-heating

C_f - Specific heat of fuel = $0.879 \frac{kJ}{kg^{O}k}$ [4]

T_f -Fuel pre-heating temp. =110 ^{0}C [Table 6.1]

T_a -Ambient temp. = 25 ^{0}C [Table 6.1]

Substituting the above data in Equation (6.25) the energy content of the fuel due to its pre heating becomes:

$$Q_{f1} = 0.0635 \frac{kg}{s} * 0.879 \frac{kJ}{kg^{O}k} (110\,^{0}C - 25\,^{0}C)$$

Q_{f1} = **4.74kW**

ii. 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.

iii. 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.

$$[Feed\ Water]_{25^{O}C} \rightarrow [Feed\ Water]_{80^{O}C} \qquad \textbf{(6.26)}$$

The energy due to pre-heating temperature can be obtained using the following equation (6.27)

$$Q_w = \dot{m}_w \times C_w \times (T_w - T_a) \qquad \textbf{(6.27)}$$

where

Q_w - Energy of feed water

$\dot{m}_w$ - Mass flow rate of feed water (6.16)

C_w -Specific heat of water = 4.18 $kJ/kg^{O}C$ [4]

T_w - Temperature of feed water = 80 ^{O}C [Table 6.2]

T_a -Ambient temperature = 25 ^{O}C [Table 6.2]

Substituting the value of the above data in Equation (6.27) the heat content in feed water becomes:

$$Q_w = \dot{m}_w \times C_w (T_w - T_a)$$

$$Q_w = 84{,}153.6\, kg/day * 4.18\, kJ/kg^{O}C * (80\ ^{O}C - 25\ ^{O}C)$$

$$Q_w = \underline{\mathbf{224\ kW}}$$

6.4.2 Analysis of the Output Energy in the Boiler

The energy output (losses) associated with the burning of furnace oil in the combustion chamber and the boiler as is indicated in Figure 6.1 includes energy loss due to:

i. Dry flue gases loss
ii. Heat loss due to evaporation of water, resulted from the formation of H_2 in fuel
iii. Heat loss due to moisture content of air
iv. Heat loss due to radition and convection from the boiler surface
v. Heat loss due to moisture content of the fuel
vi. boiler blowdown water from the boiler drum
vii. useful heat loss to steam

i. Dry Flue Gases Loss Analysis

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 (6.28).

$$\dot{Q}_{flue} = \dot{m}_{flue} C_p (T_{flue} - T_a) \qquad \textbf{(6.28)}$$

where

T_{flue}- Flue gas temperature = $224\,^oC$
T_a - Ambient temperature =$25\,^oC$
C_p - Specific heat capacity of flue gas =$1.35 \frac{kJ}{kg^{O}k}$ [4]
$\dot{m}_{flue}$ - Mass flow rate of dry flue gas

But $\dot{m}_{flue}$ is determined by multiplying the mass of dry flue gas by mass flow rate of the fuel as shown below.

m_{flue} = mass of CO_2 + mass of SO_2 + mass of N_2 + mass of O_2 the value of the constituents from flue gas mass analysis (6.1.1.2.3) is:

$CO_2 = 3.083kg$ /kg of fuel

$SO_2 = 0.03kg$ / kg of fuel

$O_2 = 3.3$ kg/ kg of fuel

$N_2 = 11$ kg + 10.72 kg = 21.72 kg/ kg of fuel

The mass of dry flue gas is 28.133 kg of dry flue gas / kg of fuel therefore $\dot{m}_{flue}$ is

$$\dot{m}_{flue} = m_{flue} \text{ x } \dot{m}_f \quad \textbf{(6.29)}$$

$$= 0.0635\frac{kg}{s} \text{ x } 28.133 \text{ kg of dry flue gas / kg of fuel}$$

$$= 1.79\frac{kg_{dry\ flue\ gas}}{s}$$

Substitute the above data and (6.29) in (6.28) energy loss due to dry flue gas is:

$$Q_{flue} = \dot{m}_{flue} C_p (T_{flue} - T_a)$$

$$= 1.79\frac{kg_{dry\ flue\ gas}}{s} \text{ x } 1.35\frac{kJ}{kg^{O}k}(224^{o}C - 24^{o}C)$$

= **481 kW**

ii. 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 librated during the combustion process. This energy loss due to presence of hydrogen in the furnace oil can be calculated as:

$$Q_{H_2} = (M)_{H_2O} * \left(\dot{m}_f\right)\left[h_{fg@25^{O}C} + C_P\left(T_{flu} - T_{amb}\right)\right] \quad \textbf{(6.30)}$$

where

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

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

$h_{fg@25^{O}C}$ - Enthalpy of water = 2441.12 kJ/kg

C_p - Specific heat capacity = $1.88\frac{kJ}{kg^{O}k}$ [4]

T_{flu} - Flue gas temperature = 224 ^oC

T_{amb} -Ambient temperature =22 ^oC

Substituting the above data in Equation (6.30) the heat loss due to evaporation of water formed due to hydrogen in the fuel is:

$$Q_{H_2} = (M)_{H_2O} * \left(\dot{m}_f\right)\left[h_{fg@25^OC} + C_P\left(T_{flu} - T_{amb}\right)\right]$$

$$= 1.08 \text{ kg water/kg fuel} * 0.0635\frac{kg}{s} [2441.12 \text{ kJ/kg} + 1.88\frac{kJ}{kg\,^Ok} (224^OC - 24^OC)]$$

= **193 kW**

iii. 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:

$$Q_{moi} = AAS * \gamma_A * \left(\dot{m}_f\right)\left[C_P\left(T_{flu} - T_{amb}\right)\right] \quad \textbf{(6.31)}$$

where

AAS - Actual air supplied 28.12 kg of air / kg of fuel

γ_A = 0.01211 kg of H_2O/kg of dry air (6.4)

Substituting the above data in Equation (6.31) the energy loss due moisture content in the combustion air is given by:

$$= 28.12 \text{ kg of air / kg of fuel} * 0.01211 \text{ kg of } H_2O\text{/kg of dry air} * 0.0635\frac{kg}{s} *$$

$$[\ 1.88\frac{kJ}{kg\,^Ok} (224^OC - 25^OC)]$$

= **7.5 kW**

iv. 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 librated during the combustion process. This energy loss due to moisture in the furnace oil is given by:

$$Q_M = (M) * \left(\dot{m}_f \right) \left[h_{fg@25^O C} + C_P \left(T_{flu} - T_{amb} \right) \right] \quad \textbf{(6.32)}$$

where

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

M - Moisture in fuel = 0.5%

$h_{fg@24^O C}$ - Enthalpy of water = 2441.12 kJ/kg

C_p - Specific heat capacity = $1.88 \dfrac{kJ}{kg\,^O k}$ [4]

T_{flue}- Flue gas temperature = $224\,^oC$

T_{amb} -Ambient temperature =$25\,^oC$

Substituting the above data in Equation (6.32), the heat loss due to evaporation of water formed due to moisture in the fuel can be calculated:

$$= 0.005 * 0.0635 \frac{kg}{s} [2441.12 \text{ kJ/kg} + 1.88 \frac{kJ}{kg\,^O k} (224^O C - 25^O C)]$$

= **0.9kW**

v. Heat loss due to Radiation and Convection from the Boiler Surface

As wind cruses over the boiler surface, energy will be lost from the boiler surface to the wind by convection. In addition to this, due to difference in temperature between the ambient air and the boiler surface there is also radiation energy loss. The energy loss due to convection and radition in watt per unit area of the boiler surface exposed to the ambient temperature condition is given by [4].

$$Q_{(i)s} = \left\{ 0.548 \left[\left(T_{(i)s} / 55.55 \right)^4 - \left(T_{(i)a} / 55.55 \right)^4 \right] + 1.957 \left(T_{(i)s} - T_{(i)a} \right)^{1.25} \sqrt{\frac{196.85V + 68.9}{68.9}} \right\} \frac{w}{m^2} * S_{(i)A} \quad \textbf{(6.33)}$$

where

T_s- Surface temperature for front, cylindrical and back is 380.7 ^{O}k, 304 ^{O}k and 315 ^{O}k respectively.

V- Wind velocity = 2.56 m/s

T_a- Local ambient temperature for front, cylindrical and back is 305 ^{O}k, 299 ^{O}k and 300.5 ^{O}k respectively.

S_A- Surface area for front, cylindrical and back is 2.41m^2, 24.74m^2 and 2.41m^2 respectively.

Substituting the values of the above data in Equation (6.33) the total heat loss due to convection and radiation is:

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

$$Q_{(i)S} = Q_{Front} + Q_{Cylinder} + Q_{Back}$$

= 3.37kw + 1.35kw + 0.45kw

= **5.17kW**

vi. Boiler Blowdown Water from the Boiler Drum

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

$$Q_b = \dot{m}_b \times h_{f@110^o C} \tag{6.34}$$

where

$h_{f@110^o C}$ - Enthalpy of blowdown = 461.3 kJ/kg

$\dot{m}_b$ - Mass flow rate of blowdown = 291.6 kg/day

Substituting the above data in Equation (6.34) the energy loss due to blow down is given

$$Q_b = \dot{m}_b \times h_{f@110^o C}$$

= 291.6 kg/day x 461.3 kJ/kg

= **1.56 kW**

Vii. The Heat Carried Away by the Steam

One of the major energy out put 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 (6.35).

$$Q_s = \dot{m}_s \times h_{gs} \tag{6.35}$$

where

$\dot{m}_s$ - Mass flow rate of steam =83,862 kg / day

h_{gs} -Enthalpy of super heated steam at a temperature of 175 ^{O}C and pressure

8 bar = $2779.95 \frac{kJ}{kg}$

Q_s -Heat carried away by the steam

Substituting the value of the above data in Equation (6.35) the heat carried away by the steam is:

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

$$Q_s = 83{,}862 \text{ kg / day} * 2779.95 \frac{kJ}{kg}$$

$$Q_s = \underline{\mathbf{2301.8\ kW}}$$

6.4.3 Analysis of Energy Losses of the Produced Steam

a) Analysis of Energy Loss Due to Vent Steam

The factory is venting the extra amount of steam produced. Vent steam is one of the major thermal energy losses of the produced steam. The thermal energy loss in the vent steam is given by Equation (6.36)

$$Q_v = \dot{m}_V \times h_{fv@125\ ^{o}C} \qquad \textbf{(6.36)}$$

where

$\dot{m}_V$ – Mass flow rate of vent steam = $0.15 \frac{kg}{s}$ (6.23)

$h_{fV@125\ ^{o}C}$ – Enthalpy of vent steam = $524.99 \frac{kJ}{kg\ ^{o}k}$

Substituting the above data in Equation (6.36) the energy loss due to vent steam is given

$$Q_v = 0.15 \frac{kg}{s} * 524.99 \frac{kJ}{kg\ ^{o}k}$$
$$= 78.75 kW$$

b) Analysis of Energy Loss Due to Throttling

The factory is reduced the produced steam temperature and pressure from 175 ^{O}C and 8 bar to different temperature and pressure as shown in Figure 6.2. The thermal energy loss due to reducing the enthalpy of steam (due to throttling) is given by Equation (6.37)

$$Q_t = \dot{m}_s \times \sum \Delta h_{gs} \tag{6.37}$$

where

$$\sum \Delta h_{gs} = \sum Enthalpy\,@\,produced\ Steam - Enthalpy\,@\,Each\ column\ \mathrm{Re}quired$$

$$= \ 305.75\frac{kJ}{kg} \quad \text{[Table 7.4]}$$

Substituting the above data in Equation (6.37) the energy loss due to throttling is:

$$Q_t = 0.828\frac{kg}{s} \times 305.75\frac{kJ}{kg} = 253.2kW$$

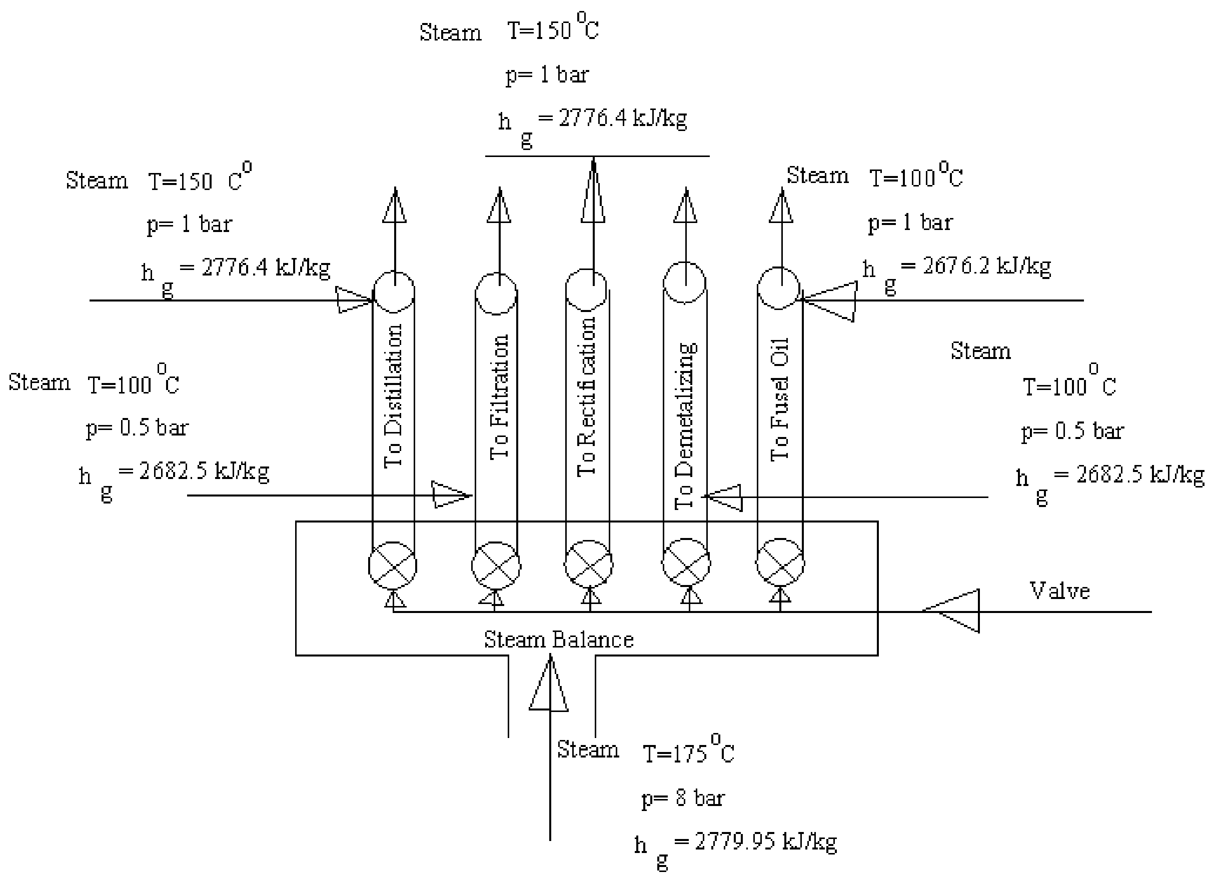


Figure 6.2 Steam pressure & temperature in columns

6.5 Analysis of Mass and Heat Balance of the Boiler

Balancing equations are used in an analysis of a process, which determines inputs and outputs of a system. There are several types of balance equations, which may prove useful in the analysis of a boiler. These include a mass balance and heat balance.

6.5.1 Analysis of Mass Balance

A mass balance is used to determine where all mass enters and leaves a system. There are two methods in which a mass balance can be performed that can be useful in the analysis of boiler. These are mass balance for the combustion process and mass balance for the working media. But the mass balance for the working fluid is already done to estimate of mass flow rate of steam.

A mass balance is used to determine all mass that enters and leaves a system. There are two methods in which a mass balance can be performed that can be useful in the analysis of boiler. These are mass balance for the combustion process and mass balance for the working media. The mass balance for the working fluid is already done to estimate of mass flow rate of steam.

Mass Balance for the Combustion Process

The mass balance for the combustion process is consisting of actual air supplied and furnace oil as an input mass and excess oxygen, nitrogen, carbon dioxide and sulphar dioxide as an output mass. Summary of mass balance for the combustion process is presented in the Table 6.7

Table 6-7 Summery of boiler input output masses

Input mass		Output mass	
Item	Mass [kg]	Item	Mass [kg]
Fuel oil	1	Excess O_2	3.3
Actual air supplied	28.12	N_2	21.72
Total	29.12	CO_2	3.083
		H_2O	1.08
		SO_2	0.03
		Total	29.19

6.5.2 Analysis of the Heat Balance

A heat balance is used to determine all the heat energy enters and leaves. Assuming that energy can neither be created nor destroyed, all energy can be accounted in a system analysis. Summary of the input-output enthalpies gives the following.

Table 6-8 Summery of Boiler Input-Output Energy

N^{O}	Input energy [kW]	N^{O}	Output energy [kW]
1	Fuel due to its heat content = 2654.3	1	Heat loss due to dry flue gas = 481
2	Fuel sensible heat = 4.74	2	Heat loss due to hydrogen in furnace oil = 193
3	Feed water = 224	3	Heat loss due to hydrogen in furnace oil = 193
4	Combustion air = 0	4	Heat loss due to moisture in air = 7.5
	$\sum_{i=1}^{4} Energy\ Inputs = 2883.04$	5	Heat loss due to moisture in fuel = 0.9
		6	Surface loss = 5.17
		7	Blowdown loss = 1.56
		8	Heat carried away by the steam = 2301.8
			$\sum_{1=1}^{7} Energy\ Losses = 2991$
			$\sum_{1=1}^{6} Energy\ Losses = 689.13$

6.5.3 Concluding Remark on the Mass and Heat Balance Result of the Boiler

The discrepancy between input output mass flow rate is 0.24%, which is an acceptable percent. This difference could be the results of measuring error. For the heat balance sheet of the boiler for 100% input energy to the boiler 96.21 % is lost. This indicates that the summation of input energy and output energy are not matching for the boiler. These discrepancies are may be due to shell energy loss of the boiler, which can be considered as energy conservation opportunities.

6.6 Efficiency of the Boiler

Boiler efficiency, which does account for radiation and convection loss, is a true indication of overall boiler efficiency. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses. As prescribed by the ASME Power Test Code, PTC 4.1, the boiler efficiency can be determined by two method; the input-output Method [28].

6.6.1 Efficiency of the Boiler Based on Input-Output Method

In this method the energy gains of the working fluid (feed water and steam) are compared with the energy content of the boiler fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula (6.38).

$$\text{Boiler efficiency} \quad \eta = \frac{\dot{m}s\left(h_{gs} - h_{fs}\right)}{\dot{m}_f\,(GCV)} \qquad \textbf{(6.38)}$$

where

$\dot{m}_s$ - Is quantity of steam generated per hour = 0.828 Kg/sec

$\dot{m}_f$ - Is quantity of fuel used per hour = 0.0635 Kg/sec

GCV- Gross calorific value of furnace oil is, 41,800 KJ/kg

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

h_{gs} -Enthalpy of super heated steam is = 2779.95 kJ/kg

The boiler working pressure and temperature are 8 bar and 175 ^{O}C respectively and also the temperature of feed water is 80°C.

Substituting the above data in Equation (6.36) the first low of efficiency by using input-output method is given by

$$\eta = \frac{\dot{m}s\left(h_{gs} - h_{fs}\right)}{\dot{m}_f\,(GCV)}$$

$$\eta = \frac{0.828\frac{kg}{s}\left(2779.95\frac{kJ}{kg} - 384.91\frac{kJ}{kg}\right)}{0.0635\frac{kg}{s}\left(41800\frac{kJ}{kg}\right)}$$

η=**74.71%**

6.6.2 Energy Efficiency of the Boiler Based on Heat Loss Method

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

i. Thermal Efficiency of the Boiler

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

$$\eta_{thGCV} = \left[1 - \frac{\sum_{i=1}^{6} Energy\ Losses}{\sum_{i=1}^{4} Energy\ Input} \right] x100\% \qquad \textbf{(6.39)}$$

Substituting the values of the summations of energy losses and energy inputs from Table 6.8 the thermal efficiency is given by

$$= \left[1 - \frac{689.13kW}{2883.04kW} \right]$$

= **<u>76.1%</u>**

ii. Combustion Efficiency of the Boiler

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

$$\eta_{Comb\ GCV} = \left[1 - \frac{\sum_{i=1}^{4} Energy\ Losses}{\sum_{i=1}^{4} Energy\ Input} \right] x100\% \qquad \textbf{(6.40)}$$

Substituting the values of the summations of energy losses and energy inputs from Table 6.8 the thermal efficiency is given by

$$= \left[1 - \frac{682.4kW}{2883.04kW} \right] x100\%$$

= **<u>76.3%</u>**

6.7 Estimation of Boiler Shell Losses

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

$$(Q_{shell})_{GCV} = \eta_{th} (\sum_{i=1}^{7} Energy\ Losses - \sum_{i=1}^{4} Energy\ Input) \qquad \textbf{(6.41)}$$

Substituting the above data from Table 6.8 in Equation (6.39) the shell energy loss is given by

$$(Q_{shell})_{GCV} = 0.761(2991\text{kW}-2883.04\text{kW})$$

$$= \underline{\mathbf{82.16\ kW}}$$

Therefore the overall efficiency of the boiler is given by adding shell energy loss to the other loss indicated in Table 6.8.

$$\eta_{Overall} = \left[1 - \frac{\sum_{i=1}^{6} Energy\ Losses + Q_{Shell(GCV)}}{\sum_{i=1}^{4} Energy\ Input}\right] x100\%$$

$$\eta_{Overall} = \left[1 - \frac{689.13kW + 82.16kW}{2883.04kW}\right] x100\%$$

$$= 73.2\ \%$$

6.8 Energy Sankey Diagram of the Boiler

The Sankey diagram is very useful tool to represent an entire input and output energy flow in any energy equipment after carrying out energy balance calculation. This diagram represents visually various output and losses so that energy managers can focus on finding improvements in a prioritised manner [28]. The energy Sankey diagram of the boiler is drawn using the heat balance sheet above and is revealed in figure 6.3.

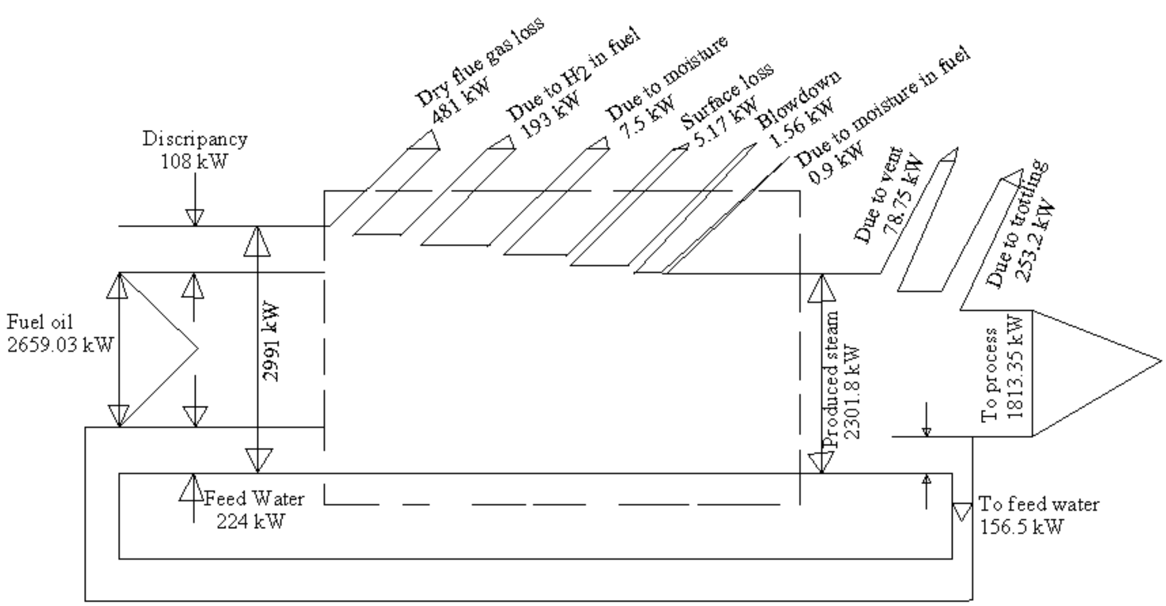


Figure 6.3 Sankey Diagram of the Boiler

6.9 General Comment of the Energy Performance of the Boiler

The energy efficiency of the boiler of the factory is found to be 71.4%. This efficiency is less than the expected performance of a new furnace oil fired boiler, which is equal to 85% [4]. The main causes that contribute to the significant drop in efficiency of the boiler is the energy loss due to

- Dry flue gas loss (16.15%)
- Hydrogen in furnace oil (6.41%)
- Moisture in combustion air (0.251%)
- Blowdown (0.0521%)
- Boiler shell loss (2.9%)
- Moisture in fuel (0.0334 %)

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

6.10 List of ECO_S Identified from Audit Analysis

From detailed energy audit conducted, the following list of energy conservation opportunities are found:

1) The flue gas temperature is greater than the recommended range due to the absence of an economizer
2) Due to the failure of water treatment plant, the boiler operates with significant shell energy losses.
3) The combustion efficiency of the boiler is low due to large percent of excess air is admitted to the combustion chamber.
4) The total steam demand of the factory is 2.13 ton/ hr, but the boiler was designed to produce 3 ton/hr. The extra amount of the produced steam is removed by means of venting and throttling, therefore the boiler is over sized.

6.11 Technical Evaluation of the ECO_S Proposed for the Boiler System

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

6.11.1 Technical Evaluation of Installing an Economizer.

The flue gas living from boiler is at a temperature of 224 ^{O}C. The higher stack temperature implies the greater percent of sensible energy loss during the combustion process this lowers the energy efficiency of the combustion process. Therefore, the stack temperature should be as low as possible. However, it should not be so low that water vapour in the exhaust condenses on the stack walls. Typically for the furnace oil, the flue gas exit temperature from a boiler is usually maintained at approximately 200 °C, so that the sulphar oxides in the flue gas do not condense and cause corrosion of heat transfer surfaces [4]. Thus reducing the stack temperature to the recommended value i.e. 200 ^{O}C for preheating the feed water offers increase in overall thermal efficiency of the boiler. Installing an economizer can reduce the flue gas exit temperature. The technical feasibility study of installing an economizer entails space availability. At current physical condition of the factory there is no adequate space to accommodate an economizer. Thus installing economizer is not technically feasible.

6.11.2 Technical Evaluation of Repairing Water Treatment Plant

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

Boiler Shell Loss

According to Equation (6.37) the shell energy loss is 82.16 kW. This loss can be minimized by controlling the TDS level of feed water (repairing water treatment plant) and mechanical cleaning of the water side of the boiler.

The technical feasibility study of repairing water treatment plant entails intensive research on the behaviours of feed water property, pressure developing unit and pressure sand filters of the water treatment plant. At the current physical condition of the factory repairing or replacing pressure developing unit and pressure sand filters of the water treatment plant are possible. Therefore repairing water treatment plant is technically feasible.

6.11.3 Technical Evaluation of Improving Efficiency of Furnace

The efficiency of a furnace oil fired boiler is 85 % on GCV [25]. From the energy analysis conducted above the efficiency of the boiler is 76.1 %. This implies that the factory furnace waste about 24 % of the energy input on gross calorific value. This waste signify that attention to the details of the energy wastages causes must be investigated and measures must be taken to improve the energy efficiency of the furnace to save energy.

The main cause of energy losses in the furnace are energy loss due to moisture content of combustion air, moisture and hydrogen content of furnace oil and excess energy loss due to dry flue gas. From the above mentioned sources of energy losses in the furnace, the only controllable loss is energy loss due to dry flue gas. This energy loss can be minimized or controlled to an optimum level through controlling the excess air admitted in to the furnace. For furnace oil fired furnace the recommended percent excess air admitted to the furnace is 15% with the volume percent of CO_2 is also 15% [4]. But the average excess air supplied to the furnace of the factory boiler is 102% with the volume percent of CO_2 being 7.8%. The technical analysis of controlling excess air is executed for the recommended percentage i.e. 15% as follows. When the excess air percentage used for combustion is changed to 15%, types of energy loss in the furnace that is affected is energy loss due to dry flue gas. To find this energy loss at 15% of excess air and the corrected efficiency the theoretical air fuel ratio, actual air supplied, mass flow rate of the flue gas and furnace temperature must be determined as is done in the audit phase.

6.11.3.1 Calculation of the Air-Fuel Ratio

a) Theoretical Air-Fuel Ratio

From Equation (6.5) the theoretical amounts of air require to burn the furnace oil at the given percent of the constituents of the furnace oil is 13.92 kg of air/kg of oil.

b) Actual Air - Fuel Ratio of Furnace oil (AA) at 15% Excess Air

Using Equation (6.6) the actual mass of air used during burning of one kg of fuel in boiler furnace can be easily found.

Actual mass of air supplied (AA) = $\left[1+\frac{EA}{100}\right]\times TheoriticalAir$ (TA) **(6.42)**

where

EA - excess air supplied = 15%

TA - theoretical amount of air fuel ratio

Substituting the values of theoretical amount of air and 15% of excess air the actual mass of air supplied to the boiler furnace is given by

$$AA = \left[1+\frac{EA}{100}\right]\times TheoriticalAir$$

= [1 + 15/100] x 13.92kg of air/kg of fuel

= 16kg of air/kg of fuel

Excess Air Quantity (EA_Q)

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

Excess air quantity = Actual air supplied - Theoretical air required **(6.43)**

= 16 kg - 13.92 kg

= 2.08 kg of air

6.11.3.2 Mass Flow Rate of Dry Flue Gas with 15% of Excess Air

In order to calculate the energy losses due to dry flue gases (stack loss), the mass flow rate of the flue gases must be calculated. To find the mass flow rate of the dry flue gases the composition of the gaseous products of the actual chemical reaction in the boiler must be determined first. The constituents of dry flue gases are CO_2, SO_2, N_2 and O_2. The mass of each constituents of dry flue gas is given by equation (6.40).

$$m_{dry\ flue} = mass\ of\ CO_2 + mass\ of\ SO_2 + mass\ of\ N_2 + mass\ of\ O_2 \qquad (6.40)$$

$$= \frac{\%\,C\times mol.wt.CO_2}{mol.wt.C} + \frac{\%\,S\times mol.wt.SO_2}{mol.wt.S} + AAS\left(\frac{77}{100}\right) + EA_Q\left(\frac{23}{100}\right)$$

$$= [\frac{0.84\times 44}{12} + \frac{0.015\times 64}{32} + 16(77/100) + 2.08(23/100)]kg\ \ flue/kg\ \ fuel$$

$$= 15.91 kg\ of\ \ dry\ \ flue\ gas/kg\ of\ \ fuel$$

Therefore mass flow rate of dry flue gas is given by equation (6.44)

$$\dot{m}_{dry\ flue} = \dot{m}_{fuel} \times m_{dry\ flue} \quad \textbf{(6.44)}$$

= 0.0635 kg/s x 15.91kg/kg

= **1.01kg of flue/sec**

6.11.3.3 Combustion Temperature of the Furnace & C_P at 15% Excess Air

For 0.5% moisture content of furnace oil at 15% of excess air the furnace temperature is 722.6 ^{O}C [7].

The formula used for determine the mean specific heat is given by (6.45)

$$C_{P_{fg}} = (0.3 + 0.000038 T_{furnace}) kcal / kg\ ^{O}C \quad \textbf{(6.45)}$$

Substitute the value of furnace temperature the specific heat at 15% excess air is given by

$$C_P = 1.368 \frac{kJ}{kg\ ^{O}C}$$

6.11.3.4 Energy Loss Due To Dry Flue Gas

The energy loss due to dry flue gas at 15% excess air can be calculated using Equation (6.46) assuming linear increase in flue gas temperature as a result of the increase in furnace temperature, the energy loss due to dry flue gas is given by

$$Q_{flue} = \dot{m}_{flue} C_P \left(T_{flue} - T_{amb} \right) \quad \textbf{(6.46)}$$

$$= 1.01\text{kg of flue/sec x } 1.368 \frac{kJ}{kg\ ^{O}C} (267.41\text{-}24)\ ^{O}\text{C}$$

= 336.31kW

Table 6.9 Heat Balance Sheet of a Boiler at 15% excess air

No	Input energy	Energy in kW
1	Fuel due to its heat content	2654.3
2	Fuel sensible heat	4.73
3	Feed water	219.85
4	Combustion air	0
	$\sum_{i=1}^{4} Energy\ Inputs$	2878.88

No	Output energy	Energy in kW
1	Heat loss due to dry flue gas	336.31
2	Heat loss due to hydrogen in furnace oil	192
3	Heat loss due to moisture in air	7.53
4	Heat loss due to moisture in fuel	0.9
	$\sum_{i=1}^{4} Energy\ Losses$	536.74

6.11.3.5 Calculation of the Combustion efficiency at 15% Excess Air

Using Equation (6.47) the combustion efficiency of the furnace at 15% of excess air is given by

$$\eta_{Comb\ GCV} = \left[1 - \frac{\sum_{i=1}^{4} Energy\ Losses}{\sum_{i=1}^{4} Energy\ Input}\right] x100\% \qquad \textbf{(6.47)}$$

$$= \left[1 - \frac{536.74kW}{2878.88}\right] x100\%$$

$$= 81.35\ \%$$

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

6.11.4 Technical Evaluation of Replacing the Existing Boiler

The existing factory boiler is design to produced 3 ton of steam per hour $@_{175\ ^oC\ \&\ 8\,bar}$. From energy analysis conducted in section (7.3.1.a) the amount of total steam consumed by factory distillery columns are 2.13 ton of steam per hour $@_{150\ ^oC\ \&\ 1\,bar}$. Due to over sizing, live steam is partly exhausted to the ambient; throttling is to bring down 8 bar pressure to 1 bar and less. This energy loss can be minimized or controlled by replacing the boiler with proper sized boiler. At the current physical condition of the factory, replacing the existing boiler with proper sized boiler is possible. Therefore, replacing the boiler is technically feasible.

6.11.5 Lists of Technically Feasible ECO$_S$

1) Repairing water treatment plant
2) Controlling the excess air by reducing fan motor power
3) Replacing the boiler with proper sized

6.12 Economic Evaluation of Technically Feasible ECO$_S$

The economic evaluation of the above technically feasible energy conservation opportunities entails determining the amount of energy saved and its cost effectiveness. These analyses for the technically feasible ECO$_S$ are done below.

6.12.1 Economic Evaluation of Repairing Water Treatment Plant

Energy saving potential, cost of spare part and direct labour costs are basic elements for economic evaluation of repairing water treatment plant.

A) Energy Saving: The energy of fuel that could be saved by repairing the water treatment plant is given by Equation (6.48)

The energy that can be saved by minimizing shell energy loss due to pre-treated feed water and mechanically cleaning the shell (water side) is given

$$Energy\ saved = \dot{m}_f\ GCV(\eta_{th} - \eta_{overall}) \qquad \textbf{(6.48)}$$

$$= 0.0635\frac{kg}{s} \times 41{,}800\frac{kJ}{kg}[0.76 - 0.732]$$

$$= 79.63\text{kW}$$

Therefore, the total amount of energy saved by repairing the water treatment plant is 79.63 kW. The equivalent litre of fuel and money saved is 49,826.66liter and 207,543 Birr per year respectively. The overall efficiency of the boiler will be.

$$\eta_{Overall} = \left[1 - \frac{\sum_{i=1}^{6} Energy\ Losses + Q_{Shell(GCV)}}{\sum_{i=1}^{4} Energy\ Input}\right] x100\%$$

$$\eta_{Overall} = \left[1 - \frac{689.13kW + 2.5kW}{2883.04kW}\right] x100\%$$

$$= 76\%$$

Therefore the increased efficiency is =76 % - 73.2 % = 2.8 %

B) Implementation Cost: According to factory cost analysis the estimated cost for repairing their water treatment plant is ranges from 20,000birr - 30,000 birr. And the cost of a typical rotating cleaning equipment for fire tube boilers ranges from $3,000-$5,000 (27,600-46,000 Birr) depending on size and feature. For a typical commercial size boiler cleaning can be accomplished in one day [7].

C) Payback Period: The simple payback period can be found by dividing the cost saved with the cost of repairing water treatment plant and cleaning equipment. Adding 47% [15] 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 x 30,000 = 44,100 birr and the cost of having the cleaning equipments will be 1.47 x 36,800 = 54,096 Birr. Thus the total cost will be 98,196 Birr.

Simple payback Period = Implementation Cost / Cost Saved **(6.49)**

= 98,196 Birr / 207,543Birr

= 0.473 year ≅ 6 months

Hence the payback period is less than a year or few months.

6.12.2 Economic Evaluation of Controlling the Excess Air by reducing motor capacity

A) Saving Analysis

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

$$\text{Energy saved} = \dot{m}_f \times GCV\left[\eta_{(cumb)15\%} - \eta_{(comb)actual}\right] \qquad \textbf{(6.50)}$$

$$= 0.0635\frac{kg}{s} \times 41{,}800\frac{kJ}{kg}[0.8135 - 0.7624]$$

$$= 135.63\text{kW}$$

The equivalent amount of fuel and money saved is 84,704.69 litre and 352,820.44 birr per year respectively.

B) Implementation Cost Analysis

The implementation cost of controlling the excess air can be attained by calculating the capacity of the fan motor in providing 15% excess air to the furnace. To calculate the fan motor capacity the optimum operating parameter of steam generators must be known in advance. From the experience obtained from the audit stay and log sheet the fan motor capacity can be calculated taking the following optimum operating parameters for the factory steam generator: steam generation 3 ton/hr at 8 bar and 175 ^{O}C super heated temperature. Feed water inlet temperature at 80 ^{O}C and exhaust gas temperature at 224 ^{O}C. To find the capacity of the fan for the above optimum parameters the following calculations are essential: the heat load, fuel consumption, and volume flow rate of flue gas and the static pressure head of the fan.

i) Calculation of Heat Load of the Boiler

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

Mathematically

$$Total\ Heat\ Load = \dot{m}(h_{g@8bar\&175^{O}C} - h_{f@8bar}) + \dot{m}_b(h_{f@110^{O}C} - h_{f@80^{O}C}) \qquad \textbf{(6.51)}$$

$$= 83{,}826\frac{kg}{day}(2779.95 - 721.11)\frac{kJ}{kg} + 291.6\frac{kg}{day}(461.3 - 334.91)\frac{kJ}{kg}$$

$$= 1705.1 kW$$

ii) Fuel Consumption of the Boiler

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

$$\text{Fuel consumption } (\dot{m}_f) = \frac{Heat\ Load}{GCV \times Efficiency} \qquad \textbf{(6.52)}$$

$$= \frac{1705.1\frac{kJ}{s}}{41800\frac{kJ}{kg} \times 0.8135}$$

$$= 0.0508 \text{ kg/s}$$

iii) Volumetric Flow Rate of Flue Gases

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

$$\dot{V} = \dot{m}_{flue} \times v_{flue} \qquad \textbf{(6.53)}$$

Calculation of the Total Mass Flow Rate of Flue Gas

The total mass flow rate of the exhaust gases produced is given by the equation (6.54) as follow

$$\dot{m}_{flue} = \dot{m}_{fuel} \times w_{flue} \qquad \textbf{(6.54)}$$

But unit weight of gas per kg of fuel is given by

w_{flue} = Actual air supplied + (1- ash)

= 16 kg of air /kg of fuel + (1 - 0)

= 17 kg / kg

Substituting Equation (6.52) and w_{flue} in Equation (6.54) the total mass flow rate of exhaust gases produced is

$$\dot{m}_{flue} = 0.0508 \frac{kg}{s} \times 17\ kg/kg = 0.864 kg\ of\ \ flue/s$$

Calculation of the Specific Volume of Wet Gas

The formula used for calculating the specific volume of the wet flue gas is given by Equation (6.55).

$$v_{flue} = v_{air} \frac{t_{flue} + 273}{t_{air} + 273} = v_{air} \frac{267.41 + 273}{24 + 273} = v_{air} 1.82 \qquad \textbf{(6.55)}$$

But the specific volume of the combustion air is calculated by Equation (6.56) as follow

$$v_{air} = \frac{RT}{P} = \frac{0.287 \times 297}{83.96} = 1.02 m^3/kg \qquad \textbf{(6.56)}$$

Thus $v_{flue} = 1.82 \times 1.02 = 1.86 m^3/kg$

Therefore the volumetric gas flow rate at flue gas temperature using Equation (6.53) is

$$\dot{V} = \dot{m}_{flue} \times v_{flue}$$

$$= 0.864 kg\ of\ \ flue/s \text{ x} 1.86 m^3/kg$$

$$= 1.61 \frac{m^3}{kg}$$

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

$$\dot{V}_{flue} = 1.2 \times 1.61 \frac{m^3}{s} = 1.93 \frac{m^3}{s}$$

iv) Calculation of Fan Static Head

The following relations give the fan static head h

h = Draft loss (in boiler + Duct + Dust collector)

= 5 +10+60 mm WC: (from factory recommended draft value)

= 75 mm WC

Taking 20% margin on head, the fan head will be h = 75 x 1.2 = 90 mm WC

v) Motor Power Capacity of the Fan

Assuming fan efficiency as 75% and motor efficiency as 90% the motor capacity for the fan is given by the equation (6.57).

$$P = \frac{\gamma_{H_2O} \dot{V}_{flue} h}{\eta_f * \eta_m} = \frac{9810 * 1.93 * 90x10^{-3}}{0.75 * 0.90} = 2.52kW \quad \textbf{(6.57)}$$

Concluding Remark on the Actual Power Rating of the Fan

The power rating of the combustion fan motor of the factory boiler is 12 kW. From motor data measurement of Table 8.1 the motor load factor is 41.6% of the rated power. This implies the actual energy supplied to the combustion fan motor is 5kw. Thus, the power supplied to the boiler motor is excess which must be reduced to improve the energy efficiency of the boiler.

vi) Implementation Cost of the Combustion Fan Motor

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

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

The yearly cost of operation is given by

Yearly Operation Cost = P * 24hr * 300days * Electricity rate

= 2.52 kW * 7200hr * 0.34 Birr/kWhr

= 6,168.96 Birr/year

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

Implementation cost of the combustion fan = 1.47 * Cost of motor + Operating cost

= 1.47 * 10,000 + 6,168.96

= 20,868.96 Birr

vii) Payback Period

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

Thus, simple payback period = Implementation Cost / Annual Cost Savings

= 20,868.96 Birr / 352,820.44 Birr/Year

= 0.06 Year

Hence the payback period is less than a month or few weeks.

6.12.3 Economic Evaluation of Replacing the Boiler

A) Saving Analysis

The energy saved in replacing the existing boiler is given by

$$\text{Energy Saved} = \dot{m}_{s(saved)} \times h_{g@8bar\&175^{O}C} \times \eta_{Comb@15\%excess\ air} \quad \textbf{(6.58)}$$

But $\dot{m}_{s(saved)} = (Steam\ produced - Steam\ demand)$

Taking 10% margin on steam demand = 2.13 x 1.1 = 2.343 ton/hr

= (3 ton/hr – 2.343 ton/hr) = 0.657ton/hr = 0.183kg/s

Substituting the above data in Equation (6.58) the saving energy is

$$= 0.183\frac{kg}{s} \times 2779.95\frac{kJ}{kg} \times 0.8135$$

$$= 413.85kW$$

The equivalent litre of fuel and money saved is 258,957.27litre and 1,078,634.5 Birr per year respectively.

B) Implementation Cost: The cost of a typical boiler (2.4 ton/hr$@1bar\ \&150^{O}C$) is ranges from \$250,000-\$300,000 (2,300,000 – 2,760,000 Birr) depending on manufacturers, whereas the salvage value the existing boiler is approximately 2,000,000 Birr.

C) Payback Period: The simple payback period can be found by dividing the cost saved with the cost of boiler. Adding 47% [15] additional cost on the direct maximum cost of purchasing the boiler for transportation and other related costs the cost of having new boiler will be 1.47 x 2,760,000 = 4,057,200 Birr.

Subtract the salvage value the implementation cost will be =2,057,200Birr

Simple payback Period = Implementation Cost / Cost Saved **(6.59)**

= 2,057,200 Birr / 1,078,634.5Birr

= 1.9 year

6.13 Summary of Technical and Economical Feasible ECO_S

The following are technical as well as economical feasible ECO_S that play crucial role in improving the boiler efficiency are

1) Repairing water treatment plant,
2) Keeping the percentage of the excess air with in the recommended rang, and
3) Replacing the existing boiler with proper sized boiler

The summery of the energy saving recommendations and the priority for post audit analysis are summarized in Table 6.10.

Table 6-10 Summery of the Energy Saving Recommendation and Priority

No.	Types of Energy Saving Recommendation	Increasing Efficiency (%)	Yearly Saving (Birr)	Capital investment (Birr)	Simple Payback (year)	Priority
1	Repairing water treatment plant	3.7	207,543	98,196	0.473	2nd
2	Replacing the existing boiler	-	1,078,634.5	4,057,200	3.77	1st
3	Controlling excess air by reducing fan motor capacity	5.1	352,820.44	20,868.96	0.06	3rd

CHAPTER 7

7 DETAILED ENERGY AUDIT OF DISTILLERY

7.1 Introduction

The major thermal energy utilizing equipment of the factory is distillery columns. Distillery columns are energy intensive part of the alcohol manufacturing system. The distillery columns are used to evaporate alcohol from water and other solutions by heating it using super heated steam produce from the boiler. Distillation of alcohol takes place by using five columns namely distillation column, filtration column, rectification column, demetalizing column and fusel oil column. The detail of these heating (distillation process) is discussed below.

Distillation column consumes an average of 1.2 kg/s of fermented wine. Fermented wine contains 25^{o}brix molasses syrups and other solutions. In this column, the separation of alcohol plus some impurities, which have low boiling points from water and other solutions demands the solution temperature to be raised from room temperature to 90 ^{O}C. Alcohol and some impurities would be sent to the filter column for farther separation of alcohol from impurities. This is accomplished by heating the solution up to 73 ^{O}C. The remaining large amount of solution which is at a temperature of 90 ^{O}C is channelled to the river as effluent. After leaving the filter column the solution (alcohol) passes through a series of connected columns for further purification process as shown in Figure 7.1.

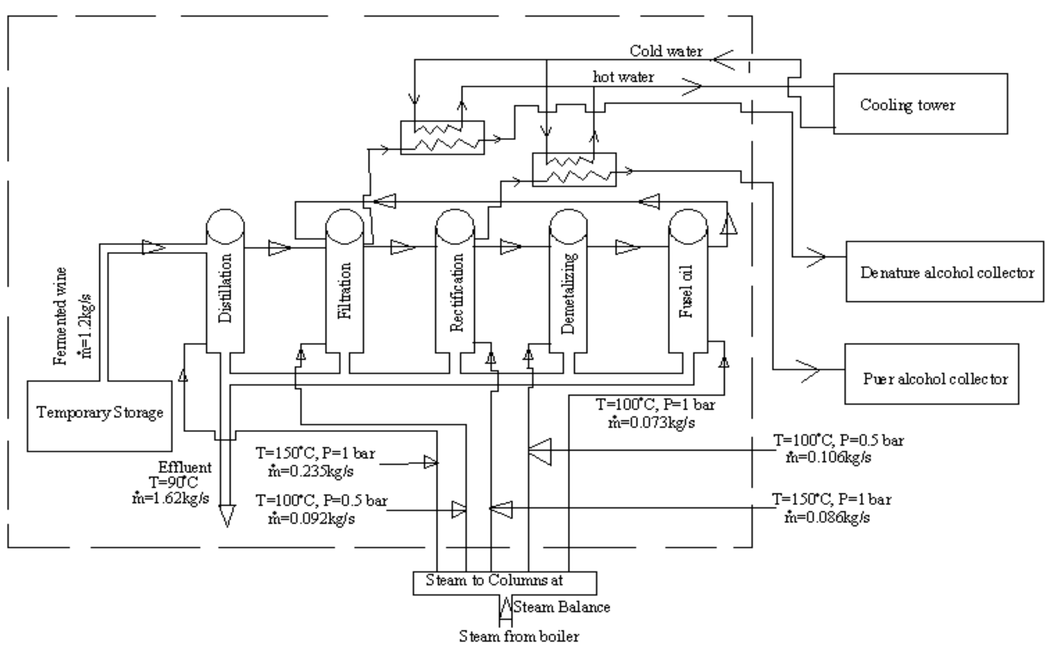


Figure 7.1 Energy and mass flow of the distillery columns

7.2 Collected Data for Conducting Detail Energy Audit of the Distillery

Inspection of manufacturing system means inspection of distillation system because it consumes all thermal energy produced by the boiler. Hence, inspection of distillation system is conducted using ultra sonic flow meter, infrared thermometer, tap rule and gage 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 each columns, these data are presented in Tables 7.1 and Table 7.2

Table 7.1 Data of Distillation Columns

Item	Distillation column	Filtration column	Rectification Column	Demetalizing column	Fuel oil column	Data collection method
Length [m]	10	12	3.73	7.75	9.15	Measured
Outside dia [m]	0.9	1	0.9	0.7	0.7	Measured
Surface Area[m^2]	28.27	37.7	10.6	17.04	20.12	Calculated
Inside dia.[m]	0.82	0.92	0.82	0.62	0.62	Measured
Ambient temp.[^OC]	41.50	42	40	47.2	42.7	Measured
Surface temp. [^OC]	86	76	67	86.5	83	Measured
Fluid temp.[^OC]	90	80	73	95	95	Gage
Volume flow rate of steam[m^3/s]	0.455	0.167	0.341	0.326	0.124	Gage
Steam pressure [bar]	1	1	0.5	0.5	1	Gage
Steam temp.[^OC]	150	150	100	100	100	Gage

Table 7-2 Data on distillation column solutions

Item	Reading	Unit	Data collection method
Density of ethanol	790	kg/m^3	From gage
Density of fermented wine	1455	kg/m^3	Catalogue
Temperature of fermented wine	28.34	^oC	Measured
Ambient temperature of fermentation room	24.21	^oC	Measured
Volume flow rate of ethanol to filter column	0.00023	m^3/s	From gage
Volume flow rate of fermented wine to distillation column	3000	l/hr	From gage
Temperature of the effluent	90	^0C	Measured
Ambient (datum) temperature	25	^0C	datum

7.3 Pre-Energy Performance Analysis of Distillery Columns

In order to perform the energy performance analysis of the distillery columns, the following parameters must be determined: the mass flow rate of effluent, mass flow rate of fermented wine, mass flow rate of steam for each columns, specific heat of fermented wine and effluent. Each parameter is discussed below.

7.3.1 Calculation of Mass Flow Rate

a) Calculation of Mass Flow Rate of Steam in each Column

The volume flow rate, temperature and pressure of steam input to each column are read from the gage mounted on the control panel and 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 amount of steam supplied to each column is calculated using equation (7.1) - (7.5).

Mass flow rate of steam consumed by distillation column

$$\dot{m}_{s(dist.)} = \dot{V}_{s(dist.)} \times \frac{1}{v_{@1bar\&150^{o}C}} \quad \textbf{(7.1)}$$

$$= 0.455\frac{m^3}{s} * 0.516\frac{kg}{m^3} = 0.235\frac{kg}{s}$$

Mass flow rate of steam consumed by filtration column

$$\dot{m}_{s(filt.)} = \dot{V}_{s(filt.)} \times \frac{1}{v_{@0.5bar\&100^{o}C}} \quad \textbf{(7.2)}$$

$$= 0.314\frac{m^3}{s} * 0.293\frac{kg}{m^3}$$

$$= 0.092\frac{kg}{s}$$

Mass flow rate of steam consumed by rectification column

$$\dot{m}_{s(rect.)} = \dot{V}_{s(rect.)} \times \frac{1}{v_{@1bar\&150^{o}C}} \quad \textbf{(7.3)}$$

$$= 0.167\frac{m^3}{s} * 0.516\frac{kg}{m^3}$$

$$= 0.086\frac{kg}{s}$$

Mass flow rate of steam consumed by demetalizing column

$$\dot{m}_{s(demt.)} = \dot{V}_{s(demt.)} \times \frac{1}{v_{@0.5bar\&100^{o}C}} \quad \textbf{(7.4)}$$

$$= 0.362\frac{m^3}{s} * 0.293\frac{kg}{m^3}$$

$$= 0.106\frac{kg}{s}$$

Mass flow rate of steam consumed by fusel oil column

$$\dot{m}_{s(fuse.)} = \dot{V}_{s(fuse.)} \times \frac{1}{v_{@1bar\&100^{o}C}} \quad \textbf{(7.5)}$$

$$= 0.124\frac{m^3}{s} * 0.589\frac{kg}{m^3}$$

$$= 0.073\frac{kg}{s}$$

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

$$\dot{m}_{S(total)} = \dot{m}_{(dist.)} + \dot{m}_{(filt)} + \dot{m}_{(rect)} + \dot{m}_{(demt)} + \dot{m}_{(fuse)} \quad \textbf{(7.6)}$$

$$= 0.235\frac{kg}{s} + 0.092\frac{kg}{s} + 0.086\frac{kg}{s} + 0.106\frac{kg}{s} + 0.073\frac{kg}{s}$$

$$= 0.592\frac{kg}{s}$$

Concluding remark on mass balance of the steam

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 deaerator as output mass. The mass balance of the steam is as shown below.

Input mass (operating) of steam = 0.828 kg/s

Output mass

Total steam supplied to each distillery columns = 0.592 kg/s

Mass flow rate of vent steam = 0.15 kg/s

Mass flow rate of deaerator steam = 0.0563 kg/s

Total output mass = 0.7983 kg/s

The difference of input and output mass of the steam is 0.0297 kg/s. This difference is due to measuring errors.

b) Calculation of Mass Flow Rate of Fermented Wine

Total amount of fermented wine sent to distillation column from fermented wine tank is 3000 lit/hr [Table 7.2]. Therefore, the total amount of mass flow rate of fermented wine can be calculated by multiplying the volume flow rate by its density.

$$\dot{m}_{wine} = \dot{V}_{wine} * \rho_{wine} \qquad \textbf{(7.7)}$$

But

$$\dot{V}_{wine} = 3000\frac{lit}{hr} * \frac{1}{1000\frac{lit}{m^3} * 3600\frac{s}{hr}} = 0.000833\frac{m^3}{s}$$

$$\rho_{wine} = 1455\frac{kg}{m^3} \text{ [25]}$$

Hence substituting the above data in Equation (7.7) the mass flow rate of fermented wine is equals to

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

$$= 0.000833\frac{m^3}{s} * 1455\frac{kg}{m^3}$$

$$= 1.21\frac{kg}{s}$$

c) Calculation of Mass Flow Rate of Ethanol

Total amount of alcohol sent to filtration column from distillation column is 828 lit/hr [Table 7.2]. Therefore, the total amount of mass flow rate of alcohol can be calculated by multiplying the volume flow rate by its density.

$$\dot{m}_{alcohol} = \dot{V}_{alcohol} * \rho_{alcohol} \qquad \textbf{(7.8)}$$

But

$$\dot{V}_{alcohol} = 828\frac{lit}{hr} * \frac{1}{1000\frac{lit}{m^3} * 3600\frac{s}{hr}} = 0.00023\frac{m^3}{s}$$

$$\rho_{alcohol} = 790\frac{kg}{m^3} \text{ [25]}$$

Hence substituting the above data in Equation (7.8) the mass flow rate of alcohol is equals to

$$\dot{m}_{alcohol} = \dot{V}_{alcohol} * \rho_{alcohol}$$

$$= 0.00023\frac{m^3}{s} * 790\frac{kg}{m^3}$$

$$= 0.182\frac{kg}{s}$$

d) Estimation of Mass Flow Rate of Effluent

Due to pipe surface corrosion, direct measurement of flow velocity of an effluent is impossible. But assuming no leakage is observed in the distillery columns we can estimate the mass flow rate of the effluent by equating mass in equal mass out in columns using equation (7.9).

$$\dot{m}_{s(total)} + \dot{m}_{wine} = \dot{m}_{effl} + \dot{m}_{alco} \qquad \textbf{(7.9)}$$

$$\dot{m}_{effl} = (\dot{m}_{s(total)} + \dot{m}_{wine}) + \dot{m}_{alco}$$

Substituting the results of equation (7.6 – 7.8) in (7.9) the mass flow rate of effluent is

$$\dot{m}_{effl} = (\dot{m}_{s(total)} + \dot{m}_{wine}) - \dot{m}_{alco}$$

$$= (0.592\frac{kg}{s} + 1.21\frac{kg}{s}) - 0.182\frac{kg}{s}$$

$$= 1.62\frac{kg}{s}$$

7.3.2 Calculation of Specific Heat

a) Specific Heat of Effluent

The specific heat of effluent during the distillation of alcohol is given by [17]

$$C_{P(eff)} = (3.14 + (0.000025(T_{eff} - T_{amb}))) \qquad \textbf{(7.10)}$$

where

T_{eff} – *Effluent temperature* = 90 ^{O}C [Table 7.2]

T_{amb} – *Ambient temperature* = 25 ^{O}C [Table 7.2]

Substituting the above data in equation (7.11) the specific heat of the effluent will be

$$C_{P(eff)} = (3.14 + (0.000025(T_{eff} - T_{amb})))$$

$$= (3.14 + (0.000025(90^{O}C - 25^{O}C)))$$

$$\cong 3.14\frac{kJ}{kg\ ^{O}C}$$

b) Specific Heat of Fermented Wine

According to [17], 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 (7.10). Therefore the specific heat of fermented wine is given by.

$$C_{P(wine)} = (3.14 + (0.000025(T_{wine} - T_{amb}))) \quad \textbf{(7.11)}$$

where

T_{wine} – Fermentation temperature = $28.34\,^{O}C$ [Table 7.2]

T_{amb} – Ambient temperature = $25\,^{O}C$ [Table 7.2]

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

$$C_{P(wine)} = (3.14 + (0.000025(28.34\ ^{O}C - 25\ ^{O}C)))$$

$$\cong 3.14 \frac{kJ}{kg\ ^{O}C}$$

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 fig 7.2.

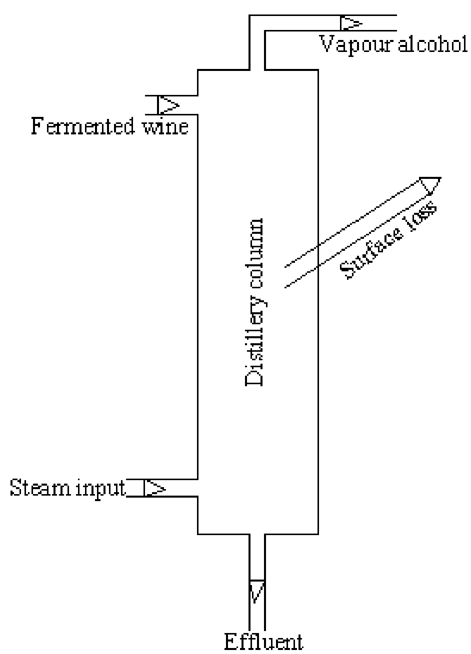


Figure 7.2 Input-output energy of the distillery

7.4.1 Analysis of the Input Energy in the Distillery

As illustrated in Figure 7.2 steam and fermented wine are the input energy of the distillery columns. The two energy sources of the distillery columns are discussed below.

i) Steam Energy to the Distillery Columns

One of the major energy sources 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 (7.12).

$$Q_{(i)s} = \dot{m}_{(i)s} \times h_{(i)gs} \qquad \textbf{(7.12)}$$

where

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

$h_{(i)gs}$ -Enthalpy of super heated steam at a given temperature and pressure [Table5.6]

Substitute the values of $\dot{m}_{(i)s}$ from equation (7.1) to (7.5) and the corresponding $h_{(i)gs}$ from steam table according to temperature and pressure values and finally the results are summarized in Table 7.3

Table 7-3 Input steam energy in distillation columns

Columns	Steam ($\dot{m}_s$)[$\frac{kg}{s}$]	Temp. [^{O}C]	Pressure [bar]	Enthalpy (h_{gs})$\frac{kJ}{kg}$	Heat input [kW]
Distillation	0.235	150	1	2776.4	652.5
Filtration	0.092	100	0.5	2682.5	246.79
Rectification	0.086	150	1	2776.4	239
Demetalizing	0.106	100	0.5	2682.5	284.34
Fusel oil	0.073	100	1	2676.2	195.4
Total					1618.03

ii) Energy in 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 (7.13).

$$Q_{wine} = \dot{m}_{wine} \times C_{P(wine)} \left(T_{wine} - T_{amb}\right) \qquad \textbf{(7.13)}$$

where

Q_{wine} – Energy of fermented wine

$\dot{m}_{wine}$ – Mass flow rate of fermented wine = $1.21 \frac{kg}{s}$ (7.7)

$C_{P(wine)}$ – Specific heat of fermented wine = $3.14 \frac{kJ}{kg\ ^{O}C}$ (7.12)

T_{wine} – Fermentation temperature = $28.34\ ^{O}C$ (Table 5.7)

T_{amb} – Ambient temperature = $25\ ^{O}C$ (Table 5.7)

Substituting the above data in Equation (6.72) input energy due to fermented wine is given

$$Q_{wine} = 1.21 \frac{kg}{s} \times 3.14 \frac{kJ}{kg\ ^{O}C} \left(28.34\ ^{O}C - 25\ ^{O}C\right)$$

$$= 12.7 \text{ kW}$$

7.4.2 Analysis of the Output Energy in the Distillery

The energy losses associated with the distillation of alcohol in the distillery columns is indicated in figure 7.2 include energy loss due to:

i. Energy loss due to effluent
ii. Columns surface loss
iii. Heat to Evaporate Alcohol

i. 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 (7.14).

$$Q_{eff} = \dot{m}_{eff}\ C_{P(eff)}\left(T_{eff} - T_{amb}\right) \qquad \textbf{(7.14)}$$

where

Q_{eff} – Energy loss with the effluent

$\dot{m}_{eff}$ – Mass flow rate of effluent = $1.53 \frac{kg}{s}$ (7.9)

$C_{P(eff)}$ – Specific heat of effluent = $3.14 \frac{kJ}{kg\ ^{O}C}$ (7.11)

T_{eff} – Effluent temperature = $90\ ^{O}C$ (Table 5.7)

T_{amb} – Ambient temperature = $25\ ^{O}C$ (table 5.7)

Substituting the above data in Equation (7.15) energy loss with the effluent is given

$$Q_{eff} = 1.53\frac{kg}{s} * 3.14\frac{kJ}{kg\ ^{O}C}\left(90\ ^{O}C - 25\ ^{O}C\right)$$

$$=312.3kW$$

ii) Heat loss due to Radiation and Convection from the Distillery Surface

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 [4].

$$Q_{(i)s} = \left\{0.548\left[\left(T_{(i)s}/55.55\right)^4 - \left(T_{(i)a}/55.55\right)^4\right] + 1.957\left(T_{(i)s} - T_{(i)a}\right)^{1.25}\sqrt{\frac{196.85V + 68.9}{68.9}}\right\}\frac{w}{m^2} * S_{(i)A} \qquad \textbf{(7.15)}$$

where

$T_{(i)S}$- Surface temperature of the ith distillery column (Table 7.1)

$T_{(i)a}$- Local ambient temperature of the ith distillery column (Table 7.1)

$S_{(i)A}$- Surface area of the ith distillery column(Table 7.1)

V- Wind velocity = 2.56 m/s

Substituting the values of the above data from (Table 7.1) in Equation (7.15) the total heat loss due to convection and radiation is summarized in Table 7.4.

Table 7-4 Heat loss from distillery surface

Columns	Ambient temperature (^{O}K)	Surface temperature (^{O}K)	Surface area (m^2)	Heat loss (kW)
Distillation	314.5	359	28.27	29.57
Filtration	313	340	10.6	5.97
Rectification	315	349	37.7	28.42
Demetalizing	320.2	359	17.04	12.31
Fusel oil	315.7	356	21.12	19.63
Total				95.90

iii) **Heat 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.

$\Rightarrow$Heat in steam + Heat in fermented wine = Heat in effluent + Heat loss by radiation and convection + Heat in vapour alcohol

Mathematically

$$Q_S + Q_{wine} = Q_{eff} + Q_{surf} + Q_{alcoh} \quad \textbf{(7.16)}$$

Rearranging Equation (7.16) yields Equation (7.17) which is the heat energy carrying by evaporation of alcohol.

$$Q_{alcoh} = (Q_S + Q_{wine}) - (Q_{surf} + Q_{eff}) \quad \textbf{(7.17)}$$

Substitute the values of Equations (7.13) to Equation (7.17) the heat energy carried by evaporation of alcohol is given by

$$Q_{alcoh} = (1619.35 \text{ kW} + 12.7 \text{ kW}) - (95.90 \text{ kW} + 312.3 \text{ KW})$$

$$= 1223.9 \text{ kW}$$

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 output and losses so that energy managers can focus on finding improvements in a prioritised manner [28]. The energy Sankey diagram of the distillery is drawn using the heat balance sheet above and is shown in Figure 7.3.

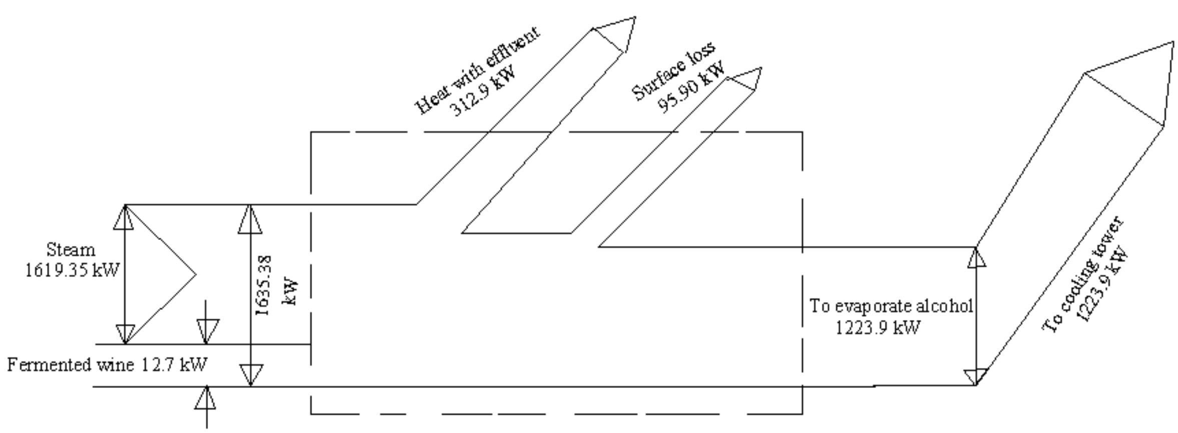


Figure 7.3 Energy Sankey Diagram of the Distillery

7.6 General Comment of the Energy Performance of the Distillery

The unwanted energy losses are energy loss from distillery surface and energy that is leaving with effluent. The energy audit results of the distillery revealed that the energy losses due to convection and radiation losses from distillery columns surfaces are 5.86% of input energy. The energy losses due to the heat that is leaving with effluent is 15.86% of the input energy. According to [17], the recommended percentage of heat carried away by the effluent is not greater than 10% 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.

7.7 List of ECO$_S$ Identified

From detailed energy audit conducted the following list of energy conservation opportunities are found:

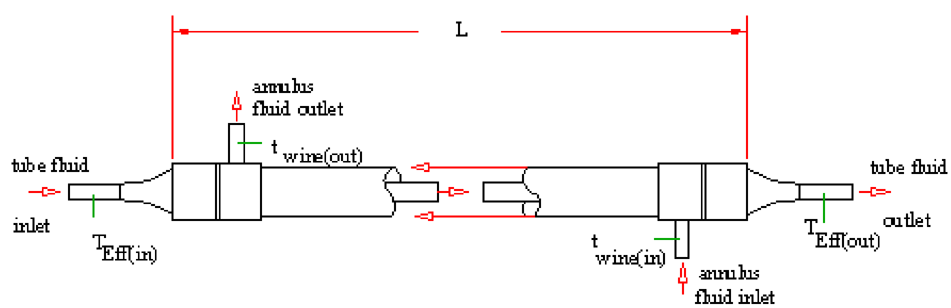
1. Recovering heat from the hot effluent

7.8 Technical Evaluation of the ECO$_S$

The technical evaluation of recovering heat from effluent is discussed below.

7.8.1 Technical Evaluation of Recovering Heat from Effluent

According to detailed energy audit of the distillery columns, 312.3kW of energy is simply thrown away with the effluent. But most of alcohol producing factories extracts heat energy from hot effluent by using different types of heat exchangers for preheating fermented wine and thereby reduces their steam consumption. According to [23], using double pipe heat exchangers, for preheating fermented wine by hot effluent, the temperature of fermented wine can be increased from 20 to 30 ^{O}C. Thus the factory must be using a heat exchanger to increase their fermented wine temperature in order to reduce steam consumption by the distillery columns. The technical evaluation to determining fermented wine temperature when the fermented wine is preheated by hot effluent is discussed below. Let the heat exchanger is counter flow type.



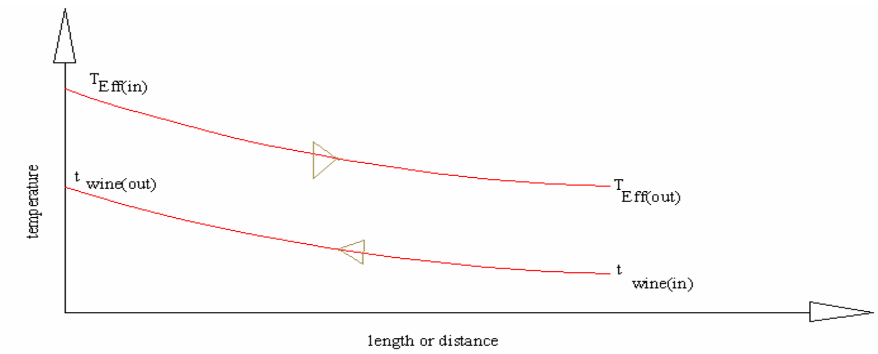


Fig 7.4 Double pipe heat exchanger

For the fermented wine, the heat transfer rate is:

$$Q_{wine} = \dot{m}_{wine}\, c_{p\,wine}\,(T_{wine(out)} - T_{wine(in)}) \qquad \textbf{(7.18)}$$

For the effluent, the heat transfer rate is:

$$Q_{eff} = \dot{m}_{eff}\, c_{p\,eff}\,(T_{eff(in)} - T_{eff(out)}) \qquad \textbf{(7.19)}$$

Assuming all heat lost by effluent is gained by the fermented wine; Equation (7.18) is set by equal to Equation (7.19):

$$\dot{m}_{eff}\, c_{p\,eff}\,(T_{eff(in)} - T_{eff(out)}) = \dot{m}_{wine}\, c_{p\,wine}\,(T_{wine(out)} - T_{wine(in)}) \qquad \textbf{(7.20)}$$

Rearranging and introducing a new variable R, $\dfrac{T_{wine(out)} - T_{wine(in)}}{T_{eff(in)} - T_{eff(out)}} = \dfrac{\dot{m}_{eff}\, C_{p(eff)}}{\dot{m}_{wine}\, C_{p(eff)}} = R$

$$\text{Then } T_{eff(out)} = T_{eff(in)} - R\left(T_{wine(out)} - T_{wine(in)}\right) \qquad \textbf{(7.21)}$$

For counter flow, the outlet temperature of the cooler fluid (fermented wine) can be ether equal or made to exceed the outlet temperature of warmer fluid (effluent). Assuming the outlet temperature of the fermented wine and effluent is equal. Rearranging Equation (7.21) gives:

$$T_{eff(out)} = T_{wine(out)} \frac{T_{eff(in)} + T_{wine(in)}}{(1+R)} \qquad \textbf{(7.22)}$$

where

Mass flow rate of the effluent = $\dot{m}_{eff} = 1.62\,\dfrac{kg}{s}$

Inlet temperature of the effluent = $T_{eff(in)} = 90^{0}$C

Inlet temperature of wine = $T_{wine(in)} = 28.34\ ^{0}$C

Specific heat the effluent $= c_{p_{eff}} = 3.14 \frac{KJ}{kg^0k}$

Specific heat the wine $= c_{p_{wine}} = 3.14 \frac{KJ}{kg^0k}$

Mass flow rate of the wine $= \dot{m}_{wine} = 1.21 \frac{kg}{s}$

Substituting the above data in Equation (7.22) the outlet temperature of the fluid is 51.52 ^{0}C, thus the fermented wine temperature will be increased by $23.18\,^OC$.

Procedure for Size Approximation

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.

It is important to fix the fluid velocity at the optimum values. The optimum velocity values for various fluids are given in appendix E, but optimum velocity value of the effluent is not included. But the constituent of effluent is 90 % of water; therefore it is possible to take the optimum value of water velocity which is 1.4 – 2.8 m/s.

Using the velocity the minimum and maximum flow area are:

$$Min\ \ flow\ area = \frac{\dot{m}_{eff}}{\rho_{eff} * V_{\max}}$$

$$= \frac{1.62 \frac{kg}{s}}{1455 \frac{kg}{m^3} \times 2.8 \frac{m}{s}} = 0.000398 m^2$$

$$Max\ \ flow\ area = \frac{\dot{m}_{eff}}{\rho_{eff} * V_{\min}}$$

$$= \frac{1.62 \frac{kg}{s}}{1455 \frac{kg}{m^3} \times 1.4 \frac{m}{s}} = 0.000795 m^2$$

Referring to appendix E, the maximum flow area correspond to approximately to 2 x 1 ¼ double pipe heat exchanger. Therefore, the tube size will be:

ID_a - Inside diameter of the annulus = 0.051 m

ID_P -Inside diameter of the pipe = 0.033 m

OD_P - Outside diameter of the pipe = 0.035 m

L - Length of the heat exchanger = 4.5 m

7.8.2 Lists of Technically Feasible ECO$_S$

1. Recover heat from effluent by using double pipe heat exchanger

7.9 Economical Evaluation of the ECO$_S$

The economic evaluation of the above technically feasible energy conservation opportunities entails determining the amount of energy saved and its cost effectiveness. These analyses for the technically feasible ECO$_S$ are done below.

7.9.1 Economical Evaluation of the Installation of Double Pipe Heat Exchanger

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.

A) Energy 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 $28.34\,^{O}C$ is 16.03 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 51.52 ^{0}C. The energy of the fermented wine that could be increased by installing a double pipe heat exchanger is given by

$$Q_{New(wine)} = \dot{m}_{wine}\left(T_{wine} - T_{amb}\right) \tag{7.23}$$

where

$Q_{New(wine)}$ – Energy gained by preheated of fermented wine

$\dot{m}_{wine}$ – Mass flow rate of fermented wine = $1.21\frac{kg}{s}$ (7.7)

$C_{P(wine)}$ – Specific heat of fermented wine = $3.14\frac{kJ}{kg\ ^{O}C}$ (7.11)

T_{wine} – Fermentation temperature = $51.52\,^{O}C$ (7.20)

T_{amb} – Ambient temperature = $24.21\,^{O}C$ (Table 5.7)

Substituting the above data in Equation (7.20) the energy gained due to preheated fermented wine is given

$$Q_{wine} = 1.21 \frac{kg}{s} \times 3.14 \frac{kJ}{kg\ ^{O}C} \left(51.52\ ^{O}C - 24.12\ ^{O}C\right)$$

$$= 104.10 \text{ kW}$$

Therefore, the net energy gained due to preheating fermented wine is 104.10 kW – 16.03 kW = 88.07 kW.

The equivalent fuel and money saved is 55,107.80 litre and 229,523.99 birr per year respectively.

B) Cost Analysis

The cost of a typical double pipe heat exchanger ranges from 50,000 – 60,000Birr depending on size, length and feature. An average effective life time of the heat exchanger is 10 years [23].

C) Payback Period

The payback period can be found by dividing the cost saved with the cost of heat exchanger. 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 x 60,000 = 88,200 Birr.

$$Payback\ Period = \frac{Cost\ of\ \ Heat\ Exchanger}{Cost\ Saved} \qquad \textbf{(7.24)}$$

$$= \frac{88{,}200\ Birr}{229{,}523.99 \frac{Birr}{Year}} \cong 0.4\ Year$$

The life time of the heat exchanger is range 10 to 15 years therefore, it is economically feasible ECO.

CHAPTER 8

8 DETAILED ENERGY AUDIT OF MOTOR AND ITS DREVEN MACHINES

8.1 Introduction

The factory used a three phase AC Induction motors, which are manufactured by an Italian company in the year from 1968 to 1972 G.C. The designed capacities of the motors are: rated power 190 kW to 1.5 kW, power factor 0.88 to 0.82 and efficiency 0.87 to 0.8. The service time and operating hours of the motors are 10 years to 20 years and 450 hours per year to 7200 hours per year respectively. The function of an electric motor is to convert electrical energy into mechanical energy. In a typical three-phase AC motor, current passes through the motor windings and creates a rotating magnetic field. The magnetic field in turn causes the motor shaft to turn. In the factory, motors are used to drive pumps, fans and an air compressor.

In order to evaluate the energy performance of motors with its driven machine; different data are gathered at motors and its driven machine by taking measurements using portable measuring instruments, referring from nameplate of the machines and annual operating hours of the machine. Therefore, the detail energy audit of these major driven machines with its motors can be performed through assessment of their energy performance according to the following categories in the sub sections of the this chapter.

- Performance evaluation of pumps with its motors
- Performance evaluation of air compressor with its motor

8.2 Performance Evaluation of Pumps with its Motors

All pumps are centrifugal, which are manufacture by an Italian company in the year from 1985 to 1991 G.C. The designed capacities of the pumps are: volume flow rate 3 m^3/hr to 60 m^3/hr and head 30 m to 45 m. The service time and operating hours of the pumps are 8 years to 12 years and 1800 hours per year to 7200 hours per year respectively. The main function of factory pumps are to transfer liquid like: fermented wine, alcohol, water and fuel from one place to other place.

In order to analyze energy performance of the pumps with their motors data must be collected from nameplate and measurements.

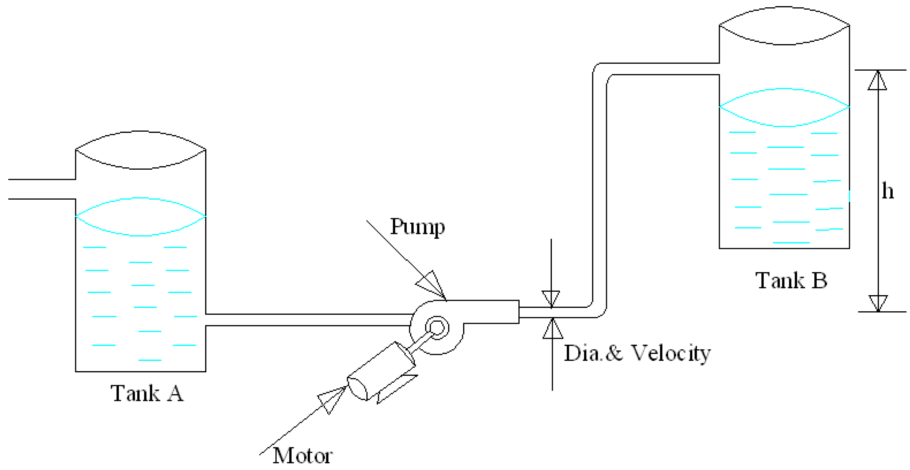


Figure 8.1 Schematic diagram of factory pump system

8.2.1 Gathered Data

Data gathered from factory pumping system, motors and pumps.

Let: A For Cooling tower pump or motor

B For Fermented wine tank pump or motor

C For Decantation tank pump or motor

D For Temporary storage tank pump or motor

E For Alcohol collector tank pump or motor

Gathered data on motors: includes nameplate: efficiency, current, voltage and power factor. And measured line current, terminals voltage and input power, these measurements are taken using portable measuring instruments.

Gathered data on pumps: it includes measured fluid flow velocity, pump head and pipe diameter. These measurements are taken using portable measuring instruments and annual operating hours and fluid density. The collected data's are presented in table 8.1 and 8.2

Table 8-1 Factory Motor Data

Motors	Service year	Rated (name plate)				Measured		
		I(A)	η **(%)**	**V**(v)	P.F	**I**(A)	**V**(v)	P (kW)
A	10	33	85	380	0.85	17.53	381.00	9.60
B	20	5	80	380	0.84	2.66	379.30	1.38
C	20	5	80	380	0.84	2.59	380.60	1.40
D	20	5	80	380	0.84	2.00	381.00	1.01
E	12	3.5	82	380	0.84	1.35	379.60	0.72

Table 8.2 Factory Pump Data

Pump	Service time (year)	Rated (Nameplate)		Measured Data				
		ΔH (m)	$\dot{Q}\ (m^3/hr)$	ρ (kg/m^3)	ΔH (m)	V(m/s)	D (m)	Operating Hours
A	10	30	60	1000	10.81	0.474	0.242	7200
B	8	40	5	1455	4.27	0.47	0.0956	1800
C	8	40	5	1455	4.38	0.49	0.0956	1800
D	8	40	5	1455	9.12	1.31	0.0508	7200
E	12	45	3	790	2.91	4.98	0.0331	7200

8.2.2 Data Analysis

In order to conduct the energy analysis and thereby to find the efficiency of pumps and motors the following parameters must be determine first.

a) Nameplate input power of the motors
b) Load factor of the motors
c) Actual power factors of the motors
d) Volume flow rate of the fluid
e) Power gained by the fluid
f) Mechanical Power
g) Pump efficiency
h) Overall Efficiency

a) Nameplate Input Power of the Motors

The nameplate input power of the motors can be calculated using equation (8.1)

$$P_R = \frac{V \times I \times PF \times \sqrt{3}}{1000} \qquad \textbf{(8.1)}$$

where
P_R - Nameplate (rated) input power
V - Rated (nameplate)
I -Rated (nameplate)

Using data from table 8.1 and substitute in equation (8.1) the name plate input power of the motors is tabulated in Table 8.3

b) Load Factor of the Motors

The load factor can be obtained by dividing the actual input power of the motor to nameplate input power of the motor. The expression used for calculating the load factor of the motors is given by equation (8.2).

$$L.F = \frac{P_{ele}}{P_{in(nameplate)}} \quad \textbf{(8.2)}$$

where

P_{ele} - Electric (measured) input power

$P_{in(nameplate)}$ - Nameplate input power

Using data from table 8.3 and substituting in Equation (8.2) the load factor of the motors of the pumps are tabulated in Table 8.3

c) Actual power factors of the motors

The actual power factor of the motors is given by equation (8.3).

$$Cos\phi = \frac{P_{ele}}{I_m * V_m * \sqrt{3}} \quad \textbf{(8.3)}$$

where

$Cos\phi$ – Power factor

$P_{in(actual)}$ - Actual (measured) input power

I_m – Measured current

V_m – Measured voltage

Using data from Table 8.1 and substitute in Equation (8.3) the actual power factor of the motor of the pumps tabulated in Table 8.3

d) Volume flow rate of the fluid

The volume flow rate of the fluid is given by Equation (8.4).

$$\dot{Q} = V_{fluid} * A_{Pipe} \quad \textbf{(8.4)}$$

where

V_{fluid} – Fluid flow velocity

A_{pipe} – Fluid flow pipe area = $\frac{\pi D^2}{4}$

Using data from Table 8.2 and substituting in Equation (8.3) the volume flow rate of the pump is tabulated in Table 8.3

e) Power gained by the fluid

The power gained by the fluid is given by Equation (8.5).

$$P_{out} = \frac{\rho \times g \times \Delta H \times \dot{Q}}{1000} \quad \textbf{(8.5)}$$

where

ρ -Density of fluid

g -Acceleration due to gravity

ΔH -Pump head

$\dot{Q}$ -Volume flow rate of fluid

f) Mechanical Power

Due to the absence of torque meter, it is mandatory to take the nameplate motor efficiency to calculate the mechanical power of the motors. Thus the mechanical power of the motor is given by Equation (8.6).

$$P_{mech} = \frac{P_{ele}}{\eta_m} \quad \textbf{(8.6)}$$

g) Pump Efficiency

The efficiency of pump is given by Equation (8.7)

$$\eta_p = \frac{P_{mech}}{P_{out}} \quad \textbf{(8.7)}$$

h) Overall efficiency

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

$$\eta_{overall} = \frac{P_{out\,(Pump)}}{P_{ele}} \quad \textbf{(8.8)}$$

where

$P_{out} -$ Power gained by the fluid

$P_{ele} -$ Electric power

Using data from Table 8.1 and Table 8.3 and substituting in Equation (8.6) the overall efficiency of pump with its motor is tabulated in Table 8.3.

Table 8.3 Summery of Data Analysis

	$P_{in(namplate)}(kW)$	P_{ele} (kW)	$P_{mec}(kW)$	$L.F$	$Cos\phi$	$\dot{Q}\ (m^3/s)$	$P_{out}(kW)$	η_p	$\eta_{Overall}$
A	18.5	9.60	8.16	0.52	0.83	0.022	2.38	0.3	0.25
B	2.8	1.38	1.1	0.49	0.79	0.0034	0.212	0.2	0.154
C	2.8	1.40	1.12	0.5	0.82	0.0035	0.223	0.2	0.16
D	2.8	1.39	1.11	0.36	0.77	0.0027	0.36	0.32	0.26
E	1.9	0.72	0.6	0.38	0.81	0.0043	0.10	0.17	0.14

8.2.3 General Comment of the Energy Performance of Pumps with its Motors

The efficiency of the pumps are: 30%, 20%, 20%, 32%, and 17%. According to [14], an average pump efficiency is 60%. Therefore the efficiencies of the five pumps are below the recommended value and this drop in efficiency of the pumping systems can be considered as an energy conservation opportunity.

8.2.4 List of ECO_S Identified

From the audit analysis of the pump with its motor the following list of energy conservation opportunities are found.

1) Leakage is observed in most pumps
2) Most motors have low power factor
3) All pumps have low efficiency

8.2.5 Technical Evaluation of the ECO_S

According to detail energy audit of the pumping system, saving energy in the factory pumping system is a question of improving pumping efficiency. In accord with this fact the result of energy audit conducted in this chapter revealed that there is a considerable energy savings potential in the pumping system of the factory through improving the pump efficiency. Hence the technical feasibility analysis of ECO_S number 1 is no cost or low cost and can be handled by routine maintenance program. For ECO_S number 2 the factory must be considered the motor power factor when the existing motors are failed or it is necessary to replace it. The technical analysis of improving efficiency of the pump by replacing the old and inefficient with new and efficient follows shortly below.

8.2.5.1 Technical Evaluation of Improving the Efficiency of the Pumps

An average efficiency of pump is 60% [14]. From the energy analysis conducted above the efficiency of the five pumps are 30%, 20%, 20%, 32%, and 17%. This implies that the factory pumps waste an average of 68 % to 83 % of the mechanical power of the motors. This energy waste signify that attention to the details of the energy wastages causes must be investigated and measures must be taken to improve the energy efficiency of the pumps and save energy. However, the survey to produce worthwhile energy savings, taking into consideration of size, pump "A" need be checked.

Pump "A" operates at 10.81m head, 79.2 m^3/hr flow rate and 8.16 kW input power. But the original design was: 30m head, 60m^3/hr flow rate and 8.16 kW input energy. Hence the pumping system runs inefficiently because its requirements differ from the original design conditions. The oversized pumps might have been installed to accommodate future increases in plant capacity. The result is an imbalance that causes the system to be inefficient and thus more expensive to operate.

$$\text{Imbalance }(\%) = [(Q_{(actual)} \text{ x } H_{(actual)})/(Q_{(Designed)} \text{ x } H_{(designed)}) - 1] \text{ x } 100\% \qquad \textbf{(8.9)}$$

where

$Q_{(actual)}$ = measured flow rate,[m^3/s]

$H_{(actual)}$ = measured discharge head, [m]

$Q_{(Designed)}$ = required flow rate, [m^3/s]

$H_{(Designed)}$ = required discharge head,[m]

Using data from Table 8.2 and Table 8.3 and substituting in Equation (8.9) percent of imbalance is:

$$\text{Imbalance }(\%) = [(0.238/0.501) -1] \text{ x}100\%$$
$$= 52.5\%$$

This implies that a pump may be incorrectly sized for current needs if it operates under throttled conditions, has a high bypass flow rate, or has a flow rate that varies from its best efficiency point (BEP) flow rate. Such pumps can be prioritized for further analysis, according to the degree of imbalance or mismatch between actual and designed conditions. Energy efficient solutions include trimming impellers, or replace the pump. From the actual factor condition trimming of the impeller is impossible due to unknown impeller diameter and lack of the pump performance curve. Hence, replacing the existing old and inefficient pump with new and efficient pump is the solution foe energy efficiency. The following parameters are essential for replacing the pump: estimation of pump efficiency, head and volume flow rate.

a) Estimation of Pump Volume Flow Rate

As illustrated in Table 8.3 the exiting pump "A" operate at a volume flow rate of 79 m^3/hr. Thus the replaced pump flow rate will be satisfying this condition.

b) Estimation of Pump head

As illustrated, in Table 8.2 the exiting pump "A" operate at a head of 10.81m. For the compensation of other minor loss add 10% margin on head, therefore the head will be 12m. Thus the replaced pump head will be 12m.

c) Estimation of pump efficiency

According to [14] an average efficiency of pump is 60%. Thus select the replaced pump at an efficiency of 60%.

d) Input Power of the Motor

The input power of the motor is given by:

$$P_{in(elec)} = \frac{\rho_{water} * g * \mathrm{H} * \dot{Q}}{\eta_m * \eta_p} \quad \textbf{(8.10)}$$

Substituting the data in Equation (8.10) the input power of the motor is

$$P_{in(elec)} = \frac{1000\frac{kg}{m^3} * 9.81\frac{m}{s^2} * 12m * 0.022\frac{m^3}{s}}{0.85 * 0.6} = 5.2kW$$

The above technical analysis indicates the input electricity is decreased by replacing the existing pump with the new one. Thus replacing the pump is technically feasibility ECO_S.

8.2.5.2 Lists of Technically Feasible ECO_S

1) Avoid leakage of pumps (House keeping).
1) Improve power factors of the motors
2) Replace the old and inefficient pump "A".

8.2.6 Economical Evaluation of the Technically Feasible ECO_S

The economic analysis of the feasible energy conservation opportunities of ECO_S 1 is no cost and/or low cost energy conservation opportunities that can be handled in routine maintenance program. The economic analysis of replacing the pump is discussed below.

8.2.6.1 Economical Evaluation of the Replacing Water Pump of the Cooling Tower

The economic analysis of the feasible energy conservation opportunities are 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.

A) Energy Saving Analysis

From the results of the energy audit analysis performed so far it is known that the energy is saved by replacing the existing pump by an average efficient pump. The energy saving analysis is given by Equation (8.11).

$$E.S = (\,P(ele)_{Old\ Pump} \ - \ P(ele)_{New\ Pump}\,) \times T_{Operating\ hours} \qquad \textbf{(8.11)}$$

where

$P(ele)_{Old\ Pump}$ - Motors input power using the existing pump = 9.6 kW [Table 8.3]

$P(ele)_{New\ Pump}$ - Motors input power using the new pump = 5.2 kW (8.10)

$T_{Operating\ hours}$ - Operating hours = 7200 hour [Table 8.2]

Substituting the above data in Equation (8.11) the saved energy is

$$E.S = ((9.6kW - 5.2kW) \times 7200hour = 31{,}680kWh / year$$

Thus, the saving cost is determined by multiplying saved energy by energy cost

$$C.S = E.S * Cost(Birr) / kWh \qquad \textbf{(8.12)}$$

where

$C.S$ - Cost saving

$Cost / kWh$ - cost per kWh = 0.34 birr/kWh [EEPC

Substituting the above data in Equation (8.12) the saving cost is

$$31{,}680kWh / year \times 0.34Birr / kWh = 10{,}771.20Birr / year$$

B) Cost Analysis

According local market analysis, the cost of an Italian made pump is approximately 10,000 Birr.

C) Payback Period

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 the cost of having the pump will be $1.1 * Cost\ of\ \ Pump$

$$Payback\ Period = \frac{1.1 * Cost\ of\ \ Pump}{Cost\ Saved} = \frac{11{,}000 Birr}{10{,}771.20 Birr / Year} \cong 1 Year$$

The approximate life time of the pump is 10 years; therefore replacing the existing cooling tower water pump is economical feasible energy conservation opportunity.

8.3 Performance Evaluation of Air Compressor with its Motor

One of the major electrical energy utilizing equipment of the factory is air compressor with its motor. The main function of factory air compressor is to operate pneumatic valve of boiler oil heater, aeration of all fermentation process and factory dust collectors. The factory use a two-stage water cooled piston type reciprocating air compressor and its motor is a three-phase AC induction. In order to analyze energy performance of the air compressor with its motors data must be collected from nameplate and measurements.

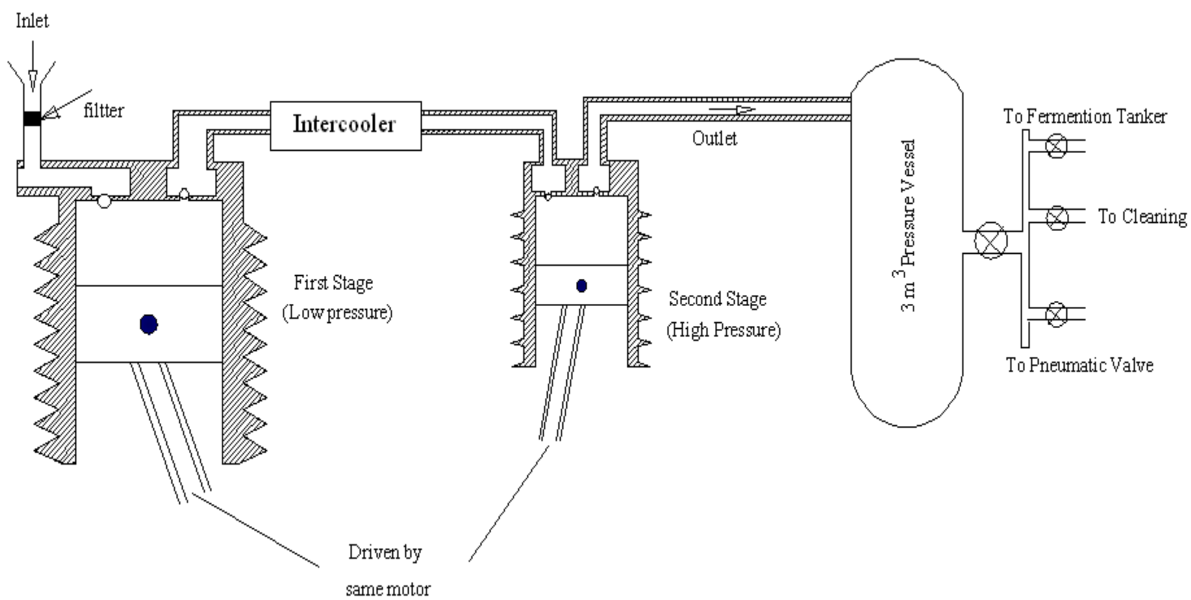


Fig 8.2 Schematic diagram of factory air compressor

8.3.1 Gathered Data

Data gathered from the factory's air compressor system and on its motors and compressor.

Gathered data on motors: it includes nameplate current, voltage, power factor and measured line current, terminals voltage and input power using portable measuring instruments.

Gathered data on air compressor: it includes measured inlet and outlet temperature of water used for cooling purpose, measured the time taken to fill $3m^3$ of pressure vessel and measured inlet air temperature. In addition to measuring the above parameter the inlet and outlet air pressure are taken from the gage mounted on compressor. The collected data are presented in Table 8.4 and 8.5.

Table 8.4 Collected Compressor Motor data

Parameter	Rated (Nameplate)	Measured	Unit
Current	190.00	130.06	Amp
Voltage	380.00	381.00	Volt
Power	-	70.35	kW
Power factor	0.84	-	-
Efficiency	0.86	-	-
Operating hours per year		450	Hour
Service years		8	Years

Table 8.5 Collected compressor data

	Reading	Unit	Data collection method
Inlet Air Temperature (T_1)	20	^0C	Measured
Outlet Pressure (P_2)	10	Bar	Gage
Pressure Vessel Volume	3	M^3	Nameplate
Time taken to rise pressure to (p_2)	193	Sec	Measured
Cooling Water at outlet	72	^0C	Measured
Cooling Water at inlet	22	^0C	Measured
Inlet pressure (P_1)	1	Atm	-
Number of stage (N)	2	-	Nameplate

8.3.2 Data Analysis

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

a) Nameplate input power of the motors
b) Load factor of the motors
c) Actual power factors of the motors
d) Volume flow rate of the air
e) Power gained by the air
f) Mechanical power

g) Compressor efficiency

h) Overall efficiency

a) Nameplate Input Power of the Motors

The nameplate input power of the motors of the compressor can be calculated using equation (8.13)

$$P_R = \frac{V \times I \times PF \times \sqrt{3}}{1000} \quad \textbf{(8.13)}$$

where

P_R - Nameplate (rated) input power

V - Rated (nameplate)

I -Rated (nameplate)

Using data from Table 8.4 and substitute in Equation (8.13) the name plate input power of the motor of the compressor is tabulated in Table 8.6.

b) Load Factor of the Motors

The load factor can be obtained by dividing the actual input power of the motor to nameplate input power of the motor. The expression used for calculating the load factor of the motors is given by equation (8.14).

$$L.F = \frac{P_{ele}}{P_R} \quad \textbf{(8.14)}$$

where

P_{ele} - Actual (measured) input power

P_R - Nameplate input power

Using data from Table 8.4 and substituting in Equation (8.14) the load factor of the motor of the compressor is tabulated in Table 8.6.

c) Actual power factors of the motors

The actual power factor of the motors is given by equation (8.15).

$$Cos\phi = \frac{P_{ele}}{I_m * V_m * \sqrt{3}} \quad \textbf{(8.15)}$$

where

$Cos\phi -$ Power factor

P_{ele} - Actual (measured) input power

$I_m -$ Measured current

$V_m -$ Measured voltage

Using data from table 8.4 and substituting in Equation (8.15) the actual power factor of the motor of the compressor is tabulated in Table 8.6.

d) Mass flow rate of the air

The mass flow rate of air deliver to the pressure vessel is given by equation (8.16).

$$\dot{m}_{air} = \frac{(P_2 - P_1) * V_{vessel}}{R * T_1} / T_{time} \qquad \textbf{(8.16)}$$

where

$\dot{m}_{air}$ -mass flow rate of air

$(P_2 - P_1)$ – The difference of compressor outlet and inlet pressure

$V_{vessel} -$ Pressure vessel used for store compressed air

$R_{air} -$ Universal gas constant =287

T_1 – Inlet air temperature

T_{time} – Time taken to rise the pressure (p_2)

Using data from Table 8.5 and substituting in Equation (8.16) the mass flow rate of the air is tabulated in Table 8.5.

e) Power gained by the fluid

The power gained by the air is given by Equation (8.17).

$$P_{Out} = \dot{m}_{air} * C_P * (T_2 - T_1) \qquad \textbf{(8.17)}$$

Temperature in terms of pressure is given by

$$= \dot{m}_{air} * C_P \left[\left(\frac{P_2}{P_1} \right)^{\frac{k-1}{N*k}} - 1 \right]$$

Using data from table 8.5 & 8.6 and substituting in Equation (8.17) the power gained by the air is tabulated in Table 8.6.

f) Mechanical Power

Due to the absence of torque meter, it is mandatory to take the nameplate motor efficiency to calculate the mechanical power of the motors. Thus the mechanical power of the motor is given by Equation (8.18).

$$P_{mech} = \frac{P_{ele}}{\eta_m} \quad \textbf{(8.18)}$$

g) Compressor Efficiency

The efficiency of pump is given by Equation (8.19)

$$\eta_C = \frac{P_{mech}}{P_{out}} \quad \textbf{(8.19)}$$

h) Overall efficiency

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

$$\eta_{overall} = \frac{P_{out\,(gained\ by\ air)}}{P_{in(actual)}} \quad \textbf{(8.20)}$$

where

P_{out} − Power gained by the air

P_{ele} − Electric energy

Using data from Table 8.6 and substituting in Equation (8.20) the overall efficiency of air compressor with its motor is tabulated in Table 8.6.

Table 8.6 Summery of Data Analysis

N^O	Parameter	Abbreviation	Calculated	Unit
1	Name plate motor power	P_R	105	kW
2	Load Factor	$L.F$	67.00	%
3	Power factor (actual)	$Cos\phi$	0.82	-
4	Mass flow rate of the air	$\dot{m}_{air}$	0.17	$\frac{kg}{s}$
5	Electric power (actual)	P_{ele}	70.35	kW
6	Power gained by the air	P_{Out}	19.37	kW
7	Mechanical power	P_{mech}	60.5	kW
8	Compressor efficiency	η_C	32.1	%
9	Overall efficiency	$\eta_{Overall}$	27.53	%

8.3.3 General Comment of the Energy Performance of Air Compressor with its Motors

With 67% of load factor of the compressor motor, the overall efficiency of factory air compressor system is 27.53 %. According to [24] the optimum value of motor load factor is ranging from 60% - 80% and power gained by the air for the reciprocating compressor is ranging 10 % to 40% of the input electric energy. Therefore both compressor load factor and overall efficiency of the compressor are within the recommended range.

8.3.4 List of ECO_S Identified

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

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

8.3.5 Technical Evaluation of the ECO_S

According to detail energy audit of the air compressor system, the motor load factor and the overall efficiency of the compressor system is within the recommended range. But still have a window for improving the production and distribution of compressed air system. In accord with this fact the result of energy audit conducted in this chapter revealed that there is a considerable energy savings potential in the compressed air system of the factory through improving the overall pumping efficiency, which reduces the energy losses, listed above. Hence the technical feasibility analyses of all ECOS number 1 to 4 are no cost or low cost and can be handled by routine maintenance program. The factory compressor maintenance program must be including the following fact points in order to save energy loss from their air compressor.

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

CHAPTER 9

9 ENERGY ACTION PLAN

9.1 Introduction

So as to improve the energy efficiency and thereby the productivity and competitiveness of Mekanissa Alcohol Factory the technically and economically feasible energy conservation opportunities identified so far must be categorized in to short term, medium term and long term action plan are stated below.

a) Short term Action

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

b) Medium Term Action

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

c) Long Term Action

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

9.2 Energy Action Team

Energy action team at the factory must be established to supervise, monitor and report the energy utilization of the factory. The tasks performed by this team includes; 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 headed by an energy team leader or manager, and consists of; Mechanical, Electrical, Process and Instrumentation crews of the factory. The energy action plan of the recommended energy conservation opportunities for post audit phase analysis is prepared in Table 9.1

Table 9-1The Energy Action Plan

S.N^{O}	Recommended ECO$_{S}$	Responsible body	Energy Action Term
1	Periodically blows soot from the boiler	Mechanical crews	Short term
2	Regularly remove scale from boiler waterside.	Mechanical crews	Short term
3	Check proper functioning of steam traps once in a shift and replace the defective	Mechanical crews	Short term
4	Clean the boiler room from dirt	Process crews	Short term
5	Control the excess air and damper position	Mechanical crews	Long term
6	Maintain the insulation of live steam lines to distillery columns	Mechanical crews & Process crews	Medium term
7	Repair the existing water treatment plant	All members	Long term
8	Regularly clean the transformer fins from dirty.	Electrical crews	Short term
9	Removes shrubs around the transformer area	Process crews	Short term
10	Install power measuring instrument for major electric appliance systems	Electrical & Instrumentation crews	Medium term
11	Hang the fluorescent lamps to the proper place.	Electrical crews	Short term
12	Replace old and incandescent lamp	Electrical crews	Medium term
13	Control compressed air distribution lines valves open when it needed	All members	Short term
14	Regularly clean the electric motors from dirt	Electrical crews & Process crews	Short term
15	Replace the low power factor motors with high power factor when it fails	Electrical crews & Process crews	Long term
16	Replace the oversized and under loaded motors with appropriate sized motors	All members	Long term
17	Regularly remove scale from distillery columns	Mechanical crews & Process crews	Short term
18	Calibrate instruments mounted on distillery columns	Instrumentation crews	Short term

$S.N^O$	Recommended ECO_S	Responsible body	Energy Action Term
19	Replace old columns trays and cups with new	Mechanical crews & Process crews	Medium term
20	Purchase portable energy instruments like combustion analyzer, thermo meter, flow meter, etc to monitor the energy efficiency of the plant regularly	Electrical & Instrumentation crews	Long term
22	Clean the shell of the boiler at mid of campaign year	Mechanical crews & Process crews	Medium term
23	Replace the existing boiler with new one for recovering vent and throttling	All members	Long term
24	Install double pipe heat exchanger for recover heat from effluent	Mechanical crews	Long term
25	Replace the cooling tower water pump	Mechanical crews	Medium term
26	Seal the pumps properly	Mechanical crews	Short term

CHAPTER 10

10 CONCULUSION AND RECOMMENDATIONS

10.1 Conclusion and Recommendations

The energy consuming systems of the factory were examined for their energy performance. The inspection identified large numbers of no/low cost energy conservation opportunities (ECO_S) and the boiler, the distillery columns, pumps & air compressor, and their prime movers of the factory were found to be the major energy consuming systems.

This thesis discussed the energy related problem of the factory and attained the thesis research objectives. The major problems of the factory in related with energy utilization were using oversized boiler, using untreated boiler feed water, unknown combustion and boiler efficiency, significant amount of energy leave with effluent, using oversized cooling tower water pump, etc. These were well addressed by the paper as discussed below.

The factory uses thermal and electric energy to produce alcohol. The energy consumption of the factory is higher than the energy consumption of the benchmark countries, for example the factory use 28,292.45 kJ of fuel oil energy and 900 kJ of electric energy to produce one litre of alcohol but the benchmark use 22,298.55 kJ of fuel oil energy and 475.2 kJ of electric energy to produce one litre of alcohol.

The standard chemical reaction of furnace oil burning on mass basis is investigated and the theoretical air-fuel ratio was found to be $13.92\frac{kg\ of\ air}{kg\ \ fuel}$. A standard procedure to determine the actual air-fuel ratios of the boiler is investigated based on the percent oxygen content of the flue gases and the value of the actual air-fuel ratio of the boiler was found to be $28.12\frac{kg\ of\ air}{kg\ \ fuel}$.
A standard mass analysis of the dry flue gases constituents and boiler blowdown analysis of the boiler is produced to help estimates the stack loss and blowdown loss respectively from the boiler.

To find the efficiency of the boiler a standard energy analysis method are used. Using this method, the combustion efficiency of the boiler was found to be 76.3%. For furnace oil fired boiler the combustion efficiency on GCV is 85% [25]. The reason for low efficiency of factory boiler is that their excess air percent is greater than the recommend value 15% [7].

There is also a significant energy loss due to boiler oversized and malfunctioning of water treatment plant. Initially the boiler was bought for another factory in Akaki, but unfortunately this factory was ceased to produce alcohol, the boiler was simply transferred to Mekanissa branch to produce steam without assessing the boiler design capacity and the factory need.

The energy efficiency of the factory was determined by using different data collected from the control panels and nameplate of the major energy consuming systems and by direct measurement using portable measuring instruments and factory record books. Therefore, the following energy conservation opportunities are recommended to implement in the factory so as to reduce its energy cost.

1. Replace the oversized boiler

The capacity of the boiler in use at the factory is 3ton/hr at 8 bar whereas the demand of the factory is 2.13ton/hr at different pressure, the maximum pressure being 1bar. Due to the over sizing, live steam is partly exhausted to the ambient; throttling is used to bring down 8 bar to 1bar and less. This is wasting 413.85 kW of input energy of the boiler. For avoiding energy loss due to the oversized boiler, through replacing the existing boiler with proper sized boiler, the technical and economical analysis is performed which resulted in energy cost saving of 1,078,634.77 Birr per year, implementation cost is 1,078,634.77 Birr and a payback period is 2 years.

2. Repair the existing water treatment plant

The feed water of the boiler in use at the factory is raw (untreated) water. Due to the malfunction of water treatment plant, scale is deposited in the water side of the boiler. The major cause of boiler shell energy loss is scale deposit in the water side of the boiler. This is wasting 82.16 kW of input energy of the boiler. For reducing energy loss due to shell resistance through repairing water treatment plant and using mechanical cleaning equipment, the technical and economical analysis is performed which resulted in efficiency gain of 3.7% of the boiler; cost saving is 207,543 Birr per year; implementation cost is 98,196 Birr and payback period is 6 months.

3. Control the Excess Air by reducing motor capacity

The power rating of the ID fan of motor of the factory is 12 kW. The actual excess air supplied by the ID fan is 102%, whereas the recommended value of excess air for furnace oil fired boiler is 15%. Due to admitting excess air beyond the recommended value, large amount of sensible heat is exhausted to the ambient through the chimney. This is wasting 144.7kW of input energy of the boiler. Keeping the excess air in the flue gas to 15% by reducing the ID fan motor capacity, technical and economical analysis were conducted which resulted in increasing combustion efficiency of the boiler by 5.05%. As a result cost saving is 352,820.44 Birr per year; implementation cost is 20,868.96 Birr and payback period is few weeks.

4. Recover Heat from Effluent

According to detailed energy audit of the distillery columns, 259.43kW of energy is simply thrown away with the effluent. But most alcohol producing factories extract heat energy from hot effluent by using different types of heat exchangers for preheating fermented wine thereby reducing their distillery steam consumption. By installing a double pipe heat exchanger to recover energy loss due to hot effluent, the technical and economical analysis were conducted which resulted in net energy gain by the fermented wine of 88.07 kW. As a result cost saving is 229,524 Birr per year; implementation cost is 88,200 Birr and payback period is 0.4 years.

5. Replace Water Pump of the Cooling Tower

The cooling tower water pump operates at 10.81m head, 79.2 m^3/hr flow rate, 8.16 kW input power and 30% efficiency. But the original design was 30m head, 60m^3/hr flow rate and 8.16 kW input energy. Due to the mismatching of best efficiency point of the pump (BEP), the pumping system runs inefficiently. This is wasting 31,680kWh/year of input energy of the motor. Through replacing a proper sized pump to reduce energy loss due to pump mismatching of best efficiency point, the technical and economical analysis is performed which resulted in cost saving of 10,771Birr per year; implementation cost is 11,000 Birr and payback period is 1year.

6. Implement No /Low Cost ECO_S

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

a. Periodic remove scale from the boiler waterside

b. Insulate the bare stem lines

c. Regularly check the proper functioning of steam traps

d. Systematically control the compressed air distribution line valves

e. Replaced the worn out trays and cups of the columns

Therefore, the audit results and the method used helps the factory to have a clear picture of its energy usage, energy efficiency and be energy self-sufficient and competent alcohol manufactures. In addition, the energy audit analysis methods and some of the energy conservation opportunities could be directly copied to other branch alcohol factories and to any energy consuming systems similar to that of Mekanissa alcohol factory with slight modifications.

10.2 FUTURE WORK

This research work recommended five major energy conservation opportunities so as to help the factory to reduce its energy cost. Therefore, from the research findings it can be said that the factory should implement the recommendation and get the benefit of the outcome thereby monitoring them.

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Appendix A
Factory Energy and Material Data

Table 4.1 Monthly Factory Energy, Material and Product Data

Billing Period (E.C)	Fuel Consumption (litre)	Electricity Consumption (kWh)	Molasses Consumption (Kg)	Alcohol Production (litre)
Mar-98	154,530.00	57,645.62	1,581,241.95	239,582.11
Apr-98	155,104.00	57,713.37	1,574,906.43	238,622.19
May-98	153,006.00	57,765.88	1,568,082.35	237,588.24
Jun-98	142,177.00	52,227.39	1,306,919.17	198,018.06
Jul-98	142,119.00	52,203.12	1,299,156.45	196,841.89
Aug-98	140,215.00	52,211.71	1,313,354.29	198,993.07
Sep-99	158,382.00	52,257.21	1,322,030.07	200,307.59
Oct-99	153,335.00	57,550.46	1,560,183.47	236,391.44
Nov-99	154,040.00	57,331.81	1,552,166.47	235,176.74
Des-99	156,296.00	57,349.68	1,544,242.39	233,976.12
Jan-99	155,982.00	57,138.56	1,536,544.25	232,809.73
Feb-99	155,673.00	57,161.65	1,528,939.07	231,657.43
Total	1,820,895.00	668,556.46	17,687,766.37	2,679,964.6

Appendix B

Specification of Major Energy Consuming Systems of the Factory

A. Specification of the Boiler

- Types of the boiler is SM/FB 300/15/N/2P-R/ELLO fire tube steam-generator
- Fabricated in 2000
- The capacity of boiler is 3ton / hr
- Designed pressure is 14 bar
- Steam temperature 175 ^{O}C
- Out side length and diameter of the boiler is 4.5m and 1.75m respectively
- Drum: thickens 16.25mm, length 3960mm and diameter 1195mm
- Use furnace oil
- Oil and feed water are pre heated 120 ^{O}C and 80 ^{O}C respectively
- Stem pressure and temperature at the out let of boiler is 8 bar and 175 ^{O}C respectively
- In the fire tube are placed tabulators that determine a high turbulence flue gases movement
- The steam separator is of multiple slots type
- The boiler is provided with front smoke box, and front cover is divided in demountable sectors.
- The front smoke box is provided with a coupling flange for the connection to the stack and a cleaning door
- The boiler is provided with fuel pump motor and water pump motor
    - Fuel pump motor
        - Fabricated in 1998
        - Type BRONZONL
        - Serial No 0129709
        - Capacity 11kw, Frequency 50 Hz, Voltage 380v
    - Water pump motor
        - Fabricated in 1998
        - Type ST132 MAZ
        - Serial No 5224703

- Capacity 12kw, Frequency 50 Hz, Voltage 380v

B. Specification of the Distillery

In the factory distillery room**,** there are five columns namely: distillation, filtration, rectification, demetallizing and fusel oil column, their feature of each column is described below:

Distillation column

- Fermented wine is feed to the distillation column at 3000 litters per hour
- Out side length and diameter are 10m and 0.9m respectively
- The internal column temperature is ranges 90-95 ^{O}C
- It has two condensers
- At the bottom of the column effluent channelled to the river with an average temperature of 90 ^{O}C

Filter column

- It filters alcohol from water and other foreign ingredients
- Out side length and diameter are 3.75m and 0.9m respectively
- The internal column temperature is 73 ^{O}C
- It has two condensers

Rectification column

- Pure alcohol is produced in this column at an amount of 170-200 litters during daytime and 200-230 during nighttimes.
- Out side length and diameter are 10m and 1m respectively
- The internal column temperature is 90 ^{O}C
- It has three condensers

Fusel oil column

- Separates undesirable oil
- It has two condensers
- Out side length and diameter are 9.15m and 0.7m respectively
- The internal column temperature is 95 ^{O}C

Demetallizing column

- Remove bad odour
- It has two condensers
- Outside length and diameter are 7.75m and 0.7m respectively

- The internal column temperature is $95^{O}C$

C. Specification of the Electric Motors

The factory uses a total of 11 motors excluding the stand-by motors, to accomplish alcohol production process. These motors have different operating parameters these are:

- Capacity vary from 90 kW to 1.5 kW
- Current consumption vary from 190 A to 3.4 A
- Voltage consumption is similar to all motors = 380 V
- Power factor vary from 0.88 to 0.82
- Efficiency vary from 87.8 to 79.8
- Operating hours vary from 7200 to 450 hours per year

Appendix C

Energy conversion factors

To:	**TJ**	**Gcal**	**Mtoe**	**MBtu**	**GWh**
From:	multiply by:				
TJ	1	238.8	2.388X10(-4)	947.8	0.2778
Gcal	4.18X10(-3)	1	10(-7)	3.968	1.16X10(-3)
Mtoe	4.18X10(4)	10(7)	1	3.968X10(7)	11630
MBtu	1.055X10(-3)	0.252	2.52X10(-8)	1	2.931X10(-4)
GWh	3.6	860	8.6X10(-5)	3412	1

Appendixes D

Questionnaire on Major Energy Consuming Systems

Boiler

Does boiler operation at high fire during most operational time?

Is a program to analyze to flue gas for proper air / fuel ratio active?

What is the measured O2 content and temperature of the flue gas?

Is a feed-water treatment program active?

Are the steam line insulate?

Are there steam leaks?

Is flue gas heat energy used for any purpose?

Air compressor

Is there an aggressive program to detect and eliminate leaks?

Air filters (air and oil) changed on a regular schedule?

Is the intake of the air located either out doors or at the coolest possible location?

Is the air-compressor system operate at the lowest acceptable line pressure for machinery using compressed air?

Is the compressor lubricated with a synthetic?

Motor

Do the motor systems employ direct drives, cog belts, or v-belts?

Are motors sized with load?

Can adjustable speed drive controls be utilized?

Pumps

Is there a programmed pump operation and monitoring?

Is there any measure taken to minimize the demand of pumps in the factory?

Is the factory used by highly efficient pumps?

Are there pumps in which there is excessive flow? Which are they?

Cooling tower

Do the condensers of the distillation columns get the appropriately cooled water?

Is the water circulated by the cooling tower soft water?

What does the condition of being exposed to dust and other rubbishes of the cooling tower look like?

Appendix E

Data for Double-Pipe Heat Exchanger

Various Fluid Velocities for Economic Diameter Tubes		
	Economic Velocity Range	
Fluid	ft / s	m / s
Acetone	4.9 - 9.8	1.5 - 3.0
Ethyl alcohol	4.8 - 9.6	1.5 – 3.0
Methyl alcohol	4.8 – 9.6	1.5 – 3.0
Propyl alcohol	4.7 – 9.4	1.4 - 2.8
Benzene	4.6 – 9.2	1.4 - 2.8
Carbon disulfide	4.2 – 8.4	1.3 – 2.6
Carbon tetrachloride	3.9 – 7.8	1.2 – 2.4
Castor oil	1.6 – 3.2	0.5 – 1.0
Chloroform	4.0 – 8.0	1.2 – 2.4
Decane	4.9 - 8.9	1.5 – 3.0
Ether	5.0 – 10.0	1.5 – 3.0
Ethylene glycol	3.9 – 7.8	1.2 – 2.4
R-11	4.0 – 8.0	1.2 – 2.4
Glycerine	1.4 – 2.8	0.43 – 0.86
Heptane	5.1 – 10.2	1.5 – 3.0
Hexane	5.2 – 10.4	1.6 – 3.2
Kerosene	4.7 – 9.4	1.4 - 2.8
Linseed oil	4.9 – 9.8	1.5 - 3.0
Mercury	2.1 – 4.2	0.64 – 1.3
Octane	5.0 – 10.0	1.5 – 3.0
Propane	5.6 – 11.2	1.7 – 3.4
Propylene	5.5 – 11.0	1.7 – 3.4
Propylene glycol	4.5 – 9.0	1.4 – 2.8
Turpylene glycol	4.6 – 9.2	1.4 – 2.8
Water	4.4 – 8.8	1.4 – 2.8

Type M Tubing [m]								$A_a=\pi OD_pL$ for L=		
Size	ID_a	ID_p	OD_p	A_p	A_a	D_h	D_e	3m	4.5m	6m
2x11/4	0.05102	0.03279	0.03404	0.000844	0.001086	0.01609	0.03954	0.3292	0.4938	0.6584
2 1/2x1 1/4	0.06338	0.03279	0.03493	0.000844	0.002196	0.02845	0.08007	0.3292	0.49938	0.6584
3 x 2	0.07572	0.05102	0.05398	0.002044	0.002214	0.02174	0.05223	0.5087	0.7631	1.017
4 x 3	0.09998	0.07572	0.07938	0.004503	0.002901	0.0206	0.04654	0.7481	1.022	1.496