

**ADDIS ABABA UNIVERSITY
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FACULTY OF TECHNOLOGY**



“Improvement of Energy Efficiency of Addis Ababa Bottle & Glass Share Company”

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ABSTRACT

Addis Ababa Bottle & Glass Share Company purchases furnace oil and electricity from National Oil Company (NOC) and Ethiopia Electric Power Corporation respectively to satisfy its primary energy demand. The prices of a liter of furnace oil and a kWh of electricity are 9.49Birr and 0.5778 Birr respectively.

The objective of the thesis is to suggest cost effective measures to improve the efficiency of energy use. The scope is to identify energy conservation opportunities to reduce energy costs and prepare an energy & documentation to implement cost effective energy utilization changes.

The methods employed to achieve the objectives of the research are: Literature review, Preliminary data collection of the company, Inspection of company energy consuming systems and equipment, Perform desktop analysis, Identify feasible Energy Conservation Opportunities (ECOs), Perform technical feasibility of the identified (ECOs), Perform economic analysis of the identified (ECOs), Prepare list of recommended energy conservation measures (ECOs) & Prepare action plan.

To evaluate the performance analysis of these major energy consuming systems, different data were collected by using portable instruments, the instruments installed on major energy systems, nameplate and referring to company log sheet and record book. The instruments are: Portable Combustion Analyzer (PCA) analyze combustion air, Infrared and dual K contact thermometer measure the surface temperature, Tape meter measure the length of the object & Vernier's calliper measure the internal pipe diameter.

Using these data pre-energy audit analyses on heating value of furnace oil, combustion property of the furnace and some of the results obtained including NCV of furnace oil is 39262.6kJ/kg & the excess air in the furnace is 136% .

To conclude that using standard methods the energy balance was conducted to determine the first law efficiency of the furnace and the corresponding energy Sankey diagram. The first law efficiency of the furnace on heat balance method is found to be 42%.

Keys words: Energy Audit, Energy Conservation Opportunities, Energy Saving & Efficiency

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CHAPTER 1

INTRODUCTION TO THE THESIS RESERCH

1.1 Background and Justification

Energy is an integral component of a modern economy. It is an essential ingredient in nearly all goods and services, but its use exacts heavy financial, environmental, and security costs. A key method of reducing energy's costs while retaining its benefits is to use it more efficiently. Industry is a very large consumer of energy. Industrial energy use and the opportunities for improving its energy efficiency depend on many technical, economic, institutional, and political factors. Many such factors have changed since the 1970s, when most energy policy was formulated[37].

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.

Engineering efficiency is the amount of useful work output that a process or a piece of equipment performs with a unit of energy input. It is expressed in units of physical output per unit of energy, or as a percentage of the input energy that is converted into useful output. A machine or a process is more energy efficient than another if it uses less energy while yielding the same output.

Energy intensity focuses on the energy use of entire industries or countries. It is expressed in units of energy per unit of physical or monetary output. It encompasses the effects of both engineering efficiency and industrial-structure. A country can lower its energy intensity by installing more energy efficient equipment and processes and/or shifting its industrial base away from heavy, processing industries toward light, fabricating ones.

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 socio-economic activities. Rather, most countries get their large proportion of energy demand from imported non-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.

The 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.

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them.

Energy can be classified into several types based on the following criteria:

- Primary and secondary energy
- Commercial and non commercial energy

- Renewable and non-renewable energy

The phrase energy management means different things to different people. To us, energy management is:

The judicious and effective use of energy to maximize profits (minimize costs) and enhance competitive positions[6].

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity.

The energy sources that are available in the market for a definite price are known as **commercial energy**. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.

The energy sources that are not available in the commercial market for a price are classified as **non-commercial energy**. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants. Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

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 fulfill 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 bottle & glass company, which is the Addis Ababa Bottle & Glass Share Company. The company is situated in the west direction of the asco road. The product of the company container glass is being used as a raw material in many areas of food & beverage packaging industries. These include: beer, Coca-Cola & ambo bottles etc.

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 Addis Ababa Bottle & Glass Share Company, 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

- ❖ Documenting results & vital information generated through these activities
- ❖ To clearly identify the types of energy and cost of energy use of the company
- ❖ 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 company so the improvements can be quantified in terms of both energy and cost.
- ❖ To obtain Sankey diagram of the energy use
- ❖ To identify and analyze improved operational techniques and/or new equipments that could substantially reduce energy use, and determine which ones are cost-effective
- ❖ To suggest cost-effective measures to improve the efficiency of energy use,
- ❖ To estimate of implementation costs and payback periods for each recommended action
- ❖ 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 company
- 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 for ECOs
- 9) Prepare action plan

1.4 Need for Energy Audit[8]

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists.

The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.

In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame.

The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a “bench-mark” (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the company.

1.5 Definition and Types of Energy Audit

1.5.1 Definition of Energy Audit

The **Energy Management Handbook** defines energy auditing as “a systematic search for energy saving opportunities.” As such, energy auditing will be a key part of an energy efficiency program, and an important means of generating ideas for measures.

An energy audit involves collecting data on the facility's operations and energy use (preferably from bills and meters).

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 programmes.

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”.

This procedure is summarized in three steps which represent the basic requirement of all energy audit:

- ✓ . Evaluating the present energy consumption
- ✓ . Identifying of energy saving possibilities
- ✓ . Reporting audit

1.5.2 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 into 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.

1.5.3 Preliminary Energy Audit

Preliminary audits seek to quantify and cost each form of energy input to a facility or organization over a period of time. They should also identify where the energy is being used within the organization. The main processes involved in such an audit are:

- Collecting data
- Analyzing data
- Presenting data

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

1.5.4 Why is Energy Wasted?

Before looking in detail at the processes involved in energy auditing, it is perhaps worth looking briefly at the reasons why energy is wasted in so many organizations. Energy is often wasted because of:

- Inadequate control systems. Heating systems may be installed without any optimum start control.
- Poor control settings. Time clock controllers may be incorrectly set so that machines are heated when not in use.
- Inefficient plant operation, often arising from the use of old or out of date technology, a situation often made worse by poor maintenance practices.
- Poor operating and working practices.

1.5.5 Detailed Energy Audit

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts

for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

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

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

The energy audit process starts with an examination of the historical and descriptive energy data for the facility. Specific data that should be gathered in this preliminary phase includes the energy bills for the past twelve months, descriptive information about the facility such as a plant layout, and a list of each piece of equipment that significantly affects the energy consumption. Before the audit begins, the auditor must know what special measurement tools will be needed. A briefing on safety procedures is also a wise precaution.

Step 1

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

➤ Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit.

During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

- ❖ Discuss with the site's senior management the aims of the energy audit.
- ❖ Discuss economic guidelines associated with the recommendations of the audit.
- ❖ Analyse the major energy consumption data with the relevant personnel.
- ❖ Obtain site drawings where available – building layout, steam distribution, compressed air distribution, electricity distribution etc.
- ❖ Tour the site accompanied by engineering/production

Step 2

The main aims of this visit are: -

- To finalise Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/ additional metering required.
- To decide whether any meters will have to be installed prior to the audit
- To identify the instrumentation required for carrying out the audit.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centres
- To create awareness through meetings/ programme

Phase II Audit Phase

Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.

The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected payback on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

The information to be collected during the detailed audit includes: -

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (eg. compressed air).

6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).
8. Energy Management procedures and energy awareness training programs within the establishment.

Existing baseline information and reports are useful to get consumption pattern, production cost and productivity levels in terms of product per raw material inputs. The audit team should collect the following baseline data:

- Technology, processes used and equipment details
- Capacity utilisation
- Amount & type of input materials used
- Water consumption
- Fuel Consumption
- Electrical energy consumption
- Other inputs such as compressed air, cooling water etc

Step 3

- ✓ Conduct survey and monitoring:-Measurement

Step 4

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

Step 5

- ✓ Identification and development of energy conservation opportunities (ECOs)

Step 6

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

Step 7

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

Step 8

- ✓ Reporting and presentation to the top management

Phase III Post Audit Phase

Step 9

- ✓ Implementation and follow up

1.6 Organization of the Thesis

This thesis research paper is organized into 9 chapters which are the necessary report arrangement of energy audit.

Chapter 1 discussed the need of conducting energy audit, the general and specific objectives of the thesis research and the meaning of energy audit, types, methodology, present brief introduction of Addis Ababa Glass & Bottle Factory including: its location, organizational structure, staff profile, the utility used by the company and operating hours.

Chapter 2 provides the main container glass production procedure and the energy demand of the company.

Chapter 3 presents the 12th month company energy bill, energy consumption pattern of other industries (benchmark), analyzed the energy bill in terms of energy intensity and comparing the energy intensity of the company with the benchmark.

Chapter 4 describes the preliminary energy audit inspection of the eight energy systems of the company to investigate no/low cost energy conservation opportunities (ECOs) and major energy systems of the company that require detailed energy audit analysis.

Chapter 5 performs extensively detailed energy audit analysis of the company furnace to determine its efficiency and the technical and economical analysis of ECOs found from the analysis.

Chapter 6 conducts detailed energy audit analysis of the company motors and their prime movers to determine their efficiency and the technical and economical analysis of ECOs found from the analysis.

Chapter 7 summarizes the technical and economical feasibility energy conservation recommendations and categorizes them as short, medium, long term, energy management,

systems, energy monitoring & control systems & energy action plans for post audit phase analysis.

Chapter 8 present the conclusion, recommendation & future work of the thesis research. In addition to the above described chapters the paper contains reference and five separate appendixes.

1.7 Introduction to Addis Ababa Glass & Bottle Share Company

Addis Ababa Glass & Bottle factory is governmental organizations which produce container glass. The Addis Ababa glass & bottle company was initially established in 1965 E.C & as share company or public enterprise in 1993 E.C. It built some parts of the company in an area of 81,000 square meters which was granted by the government of Ethiopia.

The Addis Ababa Bottle & Glass Share Company has been producing container glass 35 years and currently it has a production capacity of 5,425,995 Kilogram of container glass per year. 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 1.1 Front view of the Company

1.8 Organizational Structure of the Company

Addis Ababa Bottle & Glass Share Company is administrated by the board of directors

The Company has five departments, namely Commercial, Finance, Production & Technical, Administration & Human Resource Development, Planning and fifteen divisions. Organization structure of the company is outlined in appendix E.

1.9 Staff Profile of the Company

The total employee of the company is 528 with the following details; 129 administration (staff), 193 permanent employees' for production , 93 temporary production labourers & 113 temporary staff.

1.10 Utilities

The utilities which the company uses are water for cooling the electrode & the glass and other company utilization, electric energy for electric appliance and furnace and furnace oil for furnace.

1.10.1 Water Usage

The water source for Addis Ababa Bottle & Glass Share Company is city tap water line and underground water. The company consumes an average of 155,520 m^3 of water annually for cooling of electrode & glass and washing tankers and other purpose.

1.10.2 Fuel Usage

The major fuel supplier of the company is National Oil Company (NOC). The company purchased an average of 108 m^3 of furnace oil per annum from its supplier. The main use of this furnace oil is for producing container glass.

1.10.3 Electricity Usage

The company utilizes an average 688,571 kWh of electricity per month from national grid for maintenance operation and power supply to operate majority of its electrical appliances such as motors, pumps, fans air compressor and furnace.

1.11 Operating Hours of the Company

The company 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 2

2 CONTAINER GLASS PRODUCTION PROCESS AND THE ENERGY DEMAND

2.1 Introduction

The raw material which are used for producing container glass are sand, soda ash, limestone, cullet& silica sand. The procedure and process required for the production of container glass is by measuring each constituent using standard weighing. The energy required to perform these processes is thermal energy and electrical energy. The detail procedures and processes of container glass production of the company are discussed below.

2.2 Overview of Glass Manufacturing Processes

Glass manufacturing, regardless of the final product, requires four major processing steps: batch preparation, melting and refining, forming, and post forming. An overview of the general flow of glass manufacturing is illustrated in Figure 3-1.

Batch preparation is the step where the raw materials for glass are blended to achieve the desired final glass product. While the main components in glass are high-quality sand (silica), limestone, and soda ash, there are many other components that can be added. Once mixed the batch is charged to a melting furnace.

Melting of the batch may be accomplished in many different types and sizes of furnaces, depending upon the quantity and type of glass to be produced. The melting step is complete once the glass is free of any crystalline materials.

Refining (often referred to as fining) is the combined physical and chemical process occurring in the melting chamber during which the batch and molten glass are freed of bubbles, homogenized, and heat conditioned. After refining, the molten glass is sent to forming operations.

Forming is the step in which the final product begins to take shape, and may involve casting, blow forming, sheet forming, fiberization, or other processes. Forming processes vary widely, depending on the type of glass being manufactured.

Post-forming procedures vary widely depending upon the product. These may include processes which alter the properties of the glass, such as annealing, tempering, laminating and coating.

2.3 Process Description

There is a large variety of glass products with varying characteristics and, hence, varying production and processing routes. While recognizing the variability, the process description will

focus on the main steps that are found in Addis Ababa Bottle & Glass Share Company. The process of manufacturing quality glass is comprised of six basic steps: (1) raw materials selection, (2) batch preparation (i.e. weighing and mixing raw materials), (3) melting and refining, (4) conditioning, (5) forming, and (6) post-processing (i.e. annealing, tempering, polishing or coating). The technologies employed in each step depend on the product manufactured. Figure 3.1 gives a simplified process overview of glassmaking.

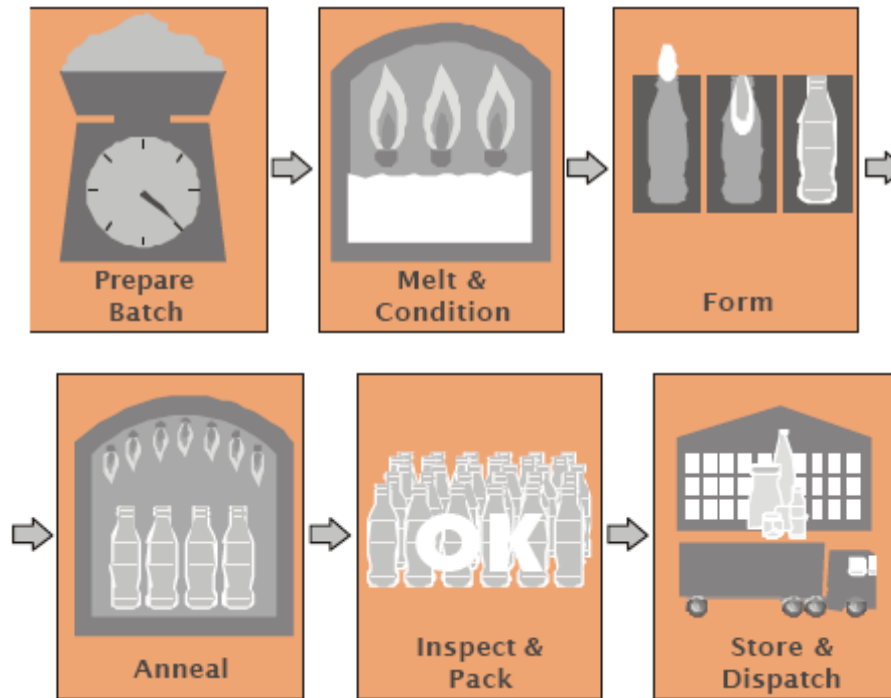


Figure 2.1 Glass Making Process

2.4 Raw Materials Selection & Batch Preparation

2.4.1 Raw Materials Selection

The glass composition determines the physical and chemical properties of the glass, and varies therefore for each product/application. Of particular interest for most applications are the chemical durability, the transmission, the softening point and the thermal expansion of the glass. Depending on their function, glass forming oxides can be grouped into network formers (for example SiO_2 , B_2O_3 , P_2O_5), intermediate oxides (for example Al_2O_3 , TiO_2 , ZrO_2), and network modifiers (for example Na_2O , CaO , MgO). A typical soda-lime glass composition used for window or container glass consists of ~60% silica sand, ~18% calcium monoxide from limestone, and ~20% sodium monoxide from soda ash; other common ingredients are feldspar,

salt cake, colorants, and refining agents (for example arsenic, sodium chloride). The use of 5 to 25 weight percent of clean cullet is not uncommon; in the case of amber container glass, sometimes more than 90 weight percent of cullet from post-consumer glass is used.

During batch preparation, the fine-ground raw materials are weighed according to the recipe, and subsequently mixed to achieve a homogenous composition. Cullet can be either mixed into the batch, or be charged into the glass melting tank simultaneously with the batch.

2.4.2 Batch Preparation

The composition of all commercially produced glass is very carefully controlled. This is achieved by purchasing relatively pure raw materials and ensuring that they are well mixed in precise proportions before being fed to the melting furnace. The daily composition of the batch for producing amber glass are silica (8673.6kg), lime stone (2439.2kg), soda ash (3633.83kg) and cullet (10909.36kg).

Although there are many differences in glass products, all glass manufacturing begin with the weighing and mixing of dry ingredients to create a “batch” or charge for the melting furnace. Many different chemical compositions can be used to create glass, and each formula affects the mechanical, electrical, chemical, optical and thermal properties of the final glass product.

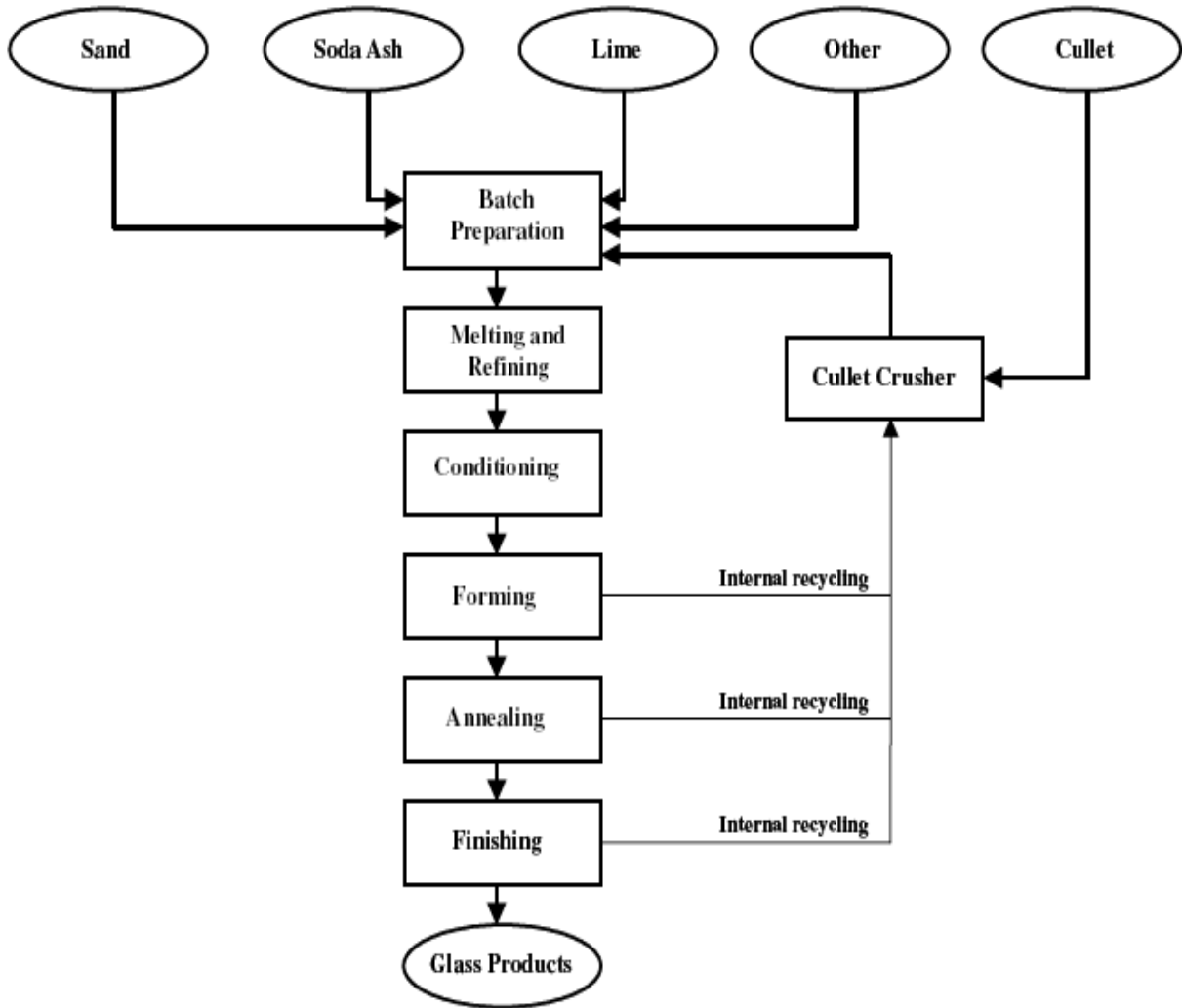


Figure 2.2 Simplified Process of Glass Manufacture

The glass batch contains formers, fluxes, stabilizers, and sometimes colorants. The basic ingredients in glass are called formers. The main former in all types of glass is silica (SiO_2) in the form of high-quality sand. A number of factors are considered when selecting sand for glass production. The cost to transport sand is 4 to 5 times the cost of the sand, and finer sands are more costly than coarse sand. Using the incorrect size sand can create melting and product quality problems. For example, container glass producers will use a relatively coarse sand with a particle size ranging from 30-100 mesh to keep costs as low as possible but still achieve the desired melting efficiency.

Raw materials are crushed, ground, and sieved prior to receipt at the glass plant, and are stored in separate elevated bins. The dry ingredients are then sent through a gravity feed system and on to a weighed and mixer. Crushed cullet is added, and the final mixture is conveyed to a batch

hopper where it stays until being dropped into the feeder to the furnace. The equipment used for crushing and handling the raw materials is generally kept separate from the furnace in what is usually called the batch plant (see Figure 3-3). Efficient blending of the dry ingredients is critically important to the quality of the glass product. If the batch is not properly blended, in-homogeneities may increase melting time and lead to product quality problems. For example, if not mixed properly, the molten glass may not have uniform viscosity, and when delivered to the forming machine will not flow evenly. The result could be a glass product of variable thickness, which is unacceptable. To ensure homogeneity of the melt extreme care is taken during batch preparation to ensure materials are of proper grain size, carefully weighed, and well-blended. Materials are generally weighed directly onto a conveyor belt which then feeds into a solids mixer. In smaller operations, batch components are weighed separately into a hopper which is rotated continuously for many hours to blend the ingredients.

2.5 Melting Tank

Glass melting, refining and conditioning are the most energy-consuming steps in the glass making process; considerable effort has therefore been placed on the optimization of the melting tank as the major piece of equipment.

2.5.1 Melting & Refining

Glasses are formed by melting crystalline materials at high temperatures. As the molten glass cools, the atoms fuse into a disordered state rather than a perfect crystal formation. Glass materials remain in this plastic state after cooling, and subsequently do not have a sharp melting or freezing point. Commercial melting of glass begins with the conversion of dry ingredients into a homogeneous molten liquid. First, the well mixed batch is charged to the melting furnace and heated to high temperatures. First, the well mixed

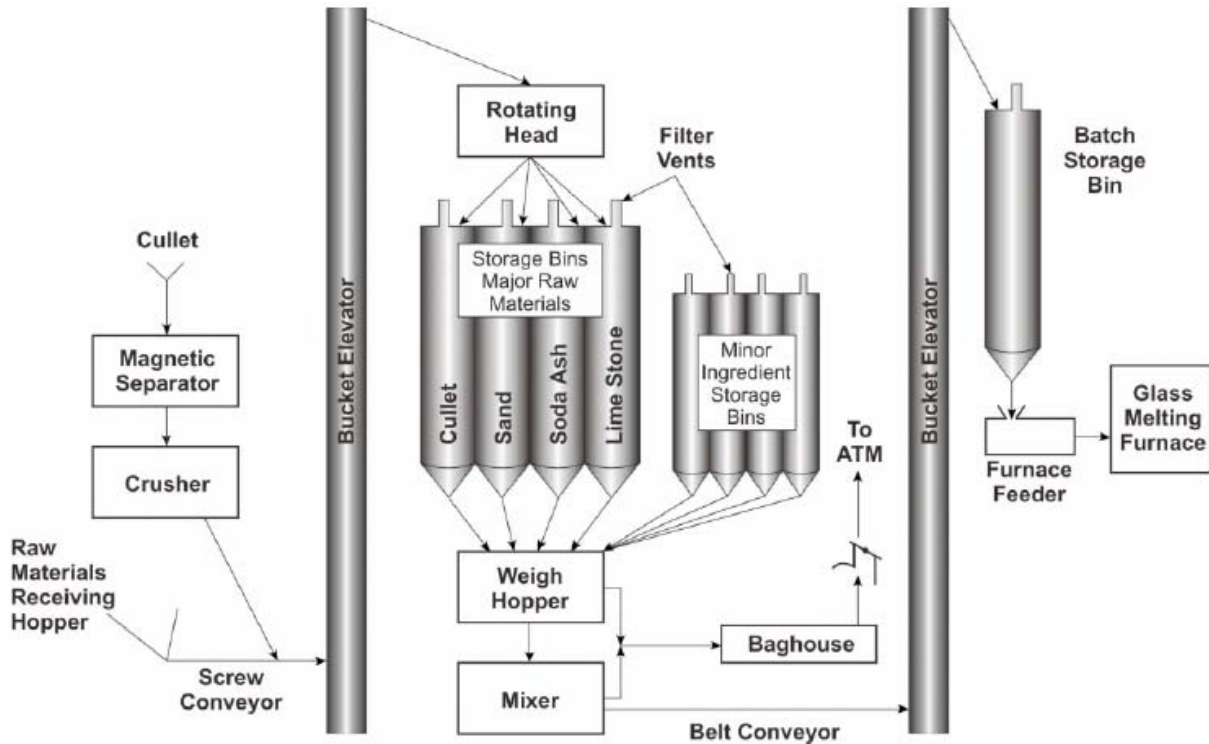


Figure 2.3 Batch Plant

batch is charged to the melting furnace and heated to temperatures ranging from 1427°C to 1704°C . As the batch is heated to these high temperatures a series of chemical reactions occur in specific order, including melting, dissolution, volatilization and oxidation reduction (redox). At about 538°C , the higher melting ingredients in the batch (e.g. sand) dissolve, a process which is accelerated by the addition of metal fluxes such as soda ash and potash which melt at lower temperatures. At this time molten sodium meta-silicate deposits on the silica grains. As heating continues to, further reactions begin to occur, and at about a liquid eutectic mixture forms between the sodium silicate and silica. At this time alkaline earth carbonates present in the limestone also begin to decompose and flux with the silica to produce molten eutectic glasses. As the batch passes through the melting furnace, it essentially goes through four phases: melting, refining, homogenizing, and heat conditioning. A rough idea of how these occur is illustrated in Figure 2-4. Melting begins when the batch enters the furnace, and is complete when the glass is free of crystalline materials. Optimally, melting should be complete before the batch has gone through the first half of the furnace. Melting rate depends on the furnace temperature, composition of the batch, grain size of the batch ingredients, amount and grain size of cullet, and homogeneity of the batch. The addition of cullet reduces the amount of time required for

melting, while poor homogeneity can seriously affect melting efficiency. During refining (often referred to as fining), gas bubbles are eliminated from the batch and molten glass. Refining occurs throughout the melting chamber, beginning with the batch charge to the furnace and continuing until the complete dissolution of crystalline materials. The refining section of the furnace is typically separated from the main melting section by a bridge wall, while glass flows through a wall opening called the throat. Imperfections (referred to as stones or cords) may be introduced into the glass during melting when the grains of dry raw material are too large to completely react by the time the flux has melted, or if the batch has not been adequately mixed. During refining these glass inclusions are eliminated or reduced. As the temperature of the glass decreases, some of the gases are reabsorbed into the melt. As these dissolve, gaseous seeds or bubbles may form containing constituents such as oxygen, sulphur dioxide, water, nitrogen, or carbon dioxide, depending on the type of glass. Refining helps to remove these seeds. Carbon dioxide is present because carbonates are used in the glass batch, whereas gases like sulphur dioxide result from the use of refining agents. Compounds such as sodium sulphate, barium oxide, boric acid, sodium chloride and calcium fluoride are used as refining agents, although they also have a role in the melting process. How much refining is done depends on the desired quality and properties of the glass. Thus, container glass will require less time and energy for refining. Homogenizing occurs throughout the melting chamber, and is finished when the properties of the glass meet the desired specifications. Perfect homogeneity exists when the glass melt exhibits no variations in the desired properties. Variations might include local differences in refractive index, density or coefficient of expansion, all of which will affect the mechanical and optical properties of the glass. Glass with excessive stones, cords, or seeds is also non-homogeneous. Factors affecting homogeneity include temperature, time, batch composition, degree of mixing, and physiochemical relations in the glass refractory system. During thermal conditioning, glass is stabilized and brought to a uniform temperature. When thermal conditioning begins is a matter of interpretation, and depends on furnace type and operating conditions.

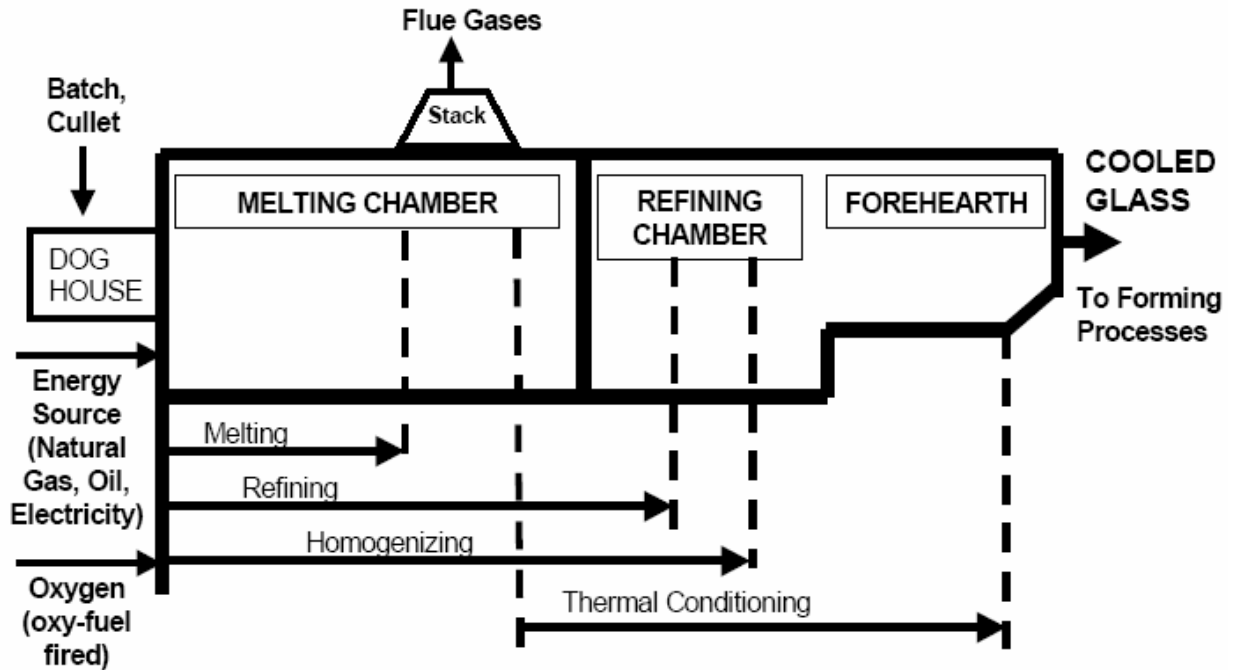


Figure 2.4 Melting and Refining Process

In general, thermal conditioning is assumed to begin immediately after the glass melt reaches its highest average temperature in the furnace, since after this time it will begin cooling to the working temperature for forming. As shown in Figure 3-4, thermal conditioning occurs in the melting and refining sections of the furnace, and in the fore hearth.

A melting furnace consists of a melting tank and a superstructure. In the melting tank the glass is molten, homogenized and fined. The used material is usually AZS

(alumina silicate plus 32 or 41% ZrO_2). The glass melt flowing from the melting end through the throat into the refiner is still far too hot for the forming process. The glass melt is cooled down 200-300°C by heat losses through the walls and by air blowing across the glass. The cooling capacity is designed to achieve sufficient cooling when working at maximum output. When the glass pull is lower, extra heat has to be supplied. The working end is often built with the same kind of materials as the melting tank.

A typical glass-melting furnace (“tank”) consists of a batch charging area (“doghouse”) attached to a refractory basin covered by a refractory superstructure (“crown”).

Common heating methods are combustion-heating (air-fuel burners) and direct electrical heating (“Joule heating”), as well as combinations of both (“electric boosting”). The company use

electric boosting. Presently, the glass furnaces in the company are heated with furnace oil & electricity.

After melting of the batch material is completed, the temperature of the furnace is typically increased to lower the melt viscosity and activate refining agents to remove bubbles from the melt (refining), and subsequently lowered to condition the glass for forming.

To keep the glass level constant, the mixture of batch and cullet is continuously charged into the glass-melting furnace to compensate for the glass withdrawn. The process of refining (also known as fining) takes place in the melting chamber. During this process, the batch of molten glass is freed of bubbles, homogenized, and heat conditioned before the glass is introduced into the fore hearth.

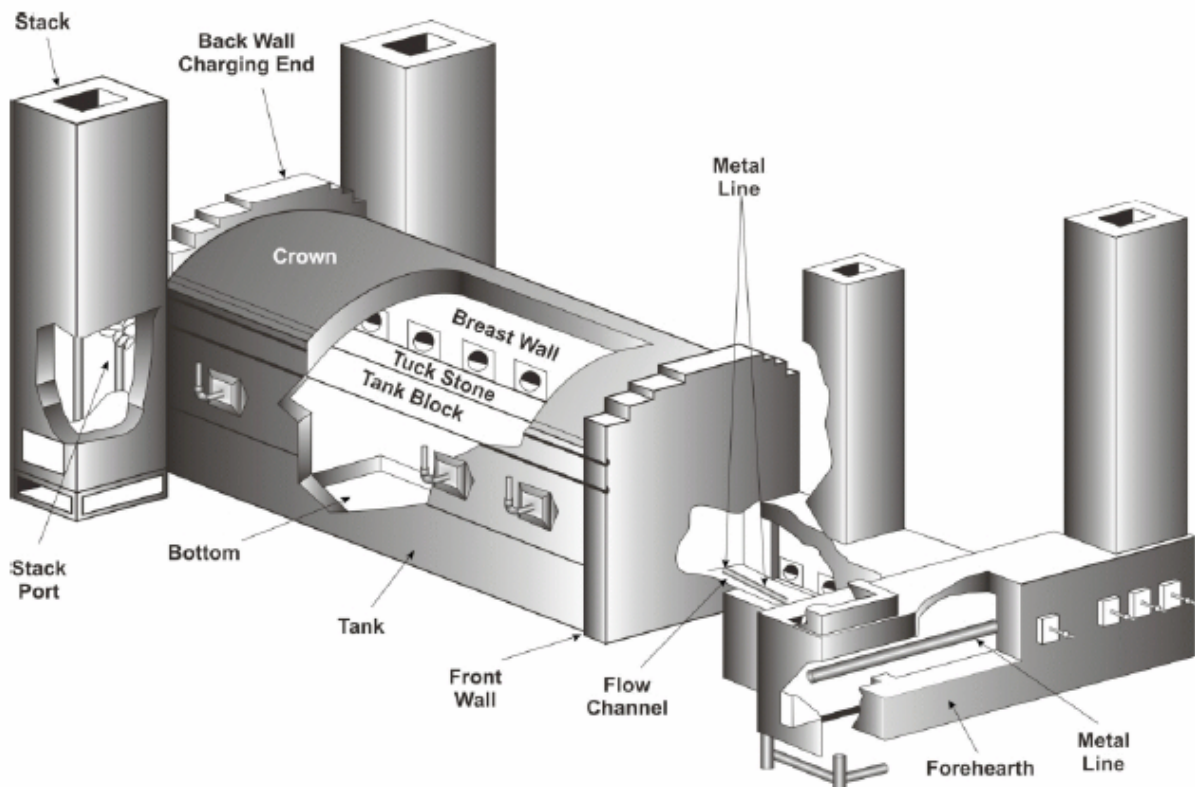


Figure 2.5 Schematic Diagram of Furnace

The process of refining (also known as fining) takes place in the melting chamber. During this process, the batch of molten glass is freed of bubbles, homogenized, and heat conditioned before the glass is introduced into the fore hearth. The role of the fore hearth is to condition the glass.

Conditioning produces a stable, desired glass temperature, evenly distributed both vertically and laterally. Many defects are related to the temperature and result from the lack of thermal homogeneity of the glass, directly related to the conditioning of the fore hearth.

2.5.2 Conditioning

After completion of the refining stage the fairly homogenous, bubble-free glass leaves the tank and enters the fore hearth, sometimes through a specifically designed pathway (channel, “throat”). Main function of the fore hearth is to condition the glass, i.e. to deliver glass with the desired temperature and temperature distribution to the forming process. Deviations from the desired thermal profile can cause undesirable differences in viscosity, and subsequently lead to visible defects in the finished product. Fore hearths can be electrically heated.

2.5.3 Forming

The conditioned glass is delivered from the fore hearth to the forming equipment at a constant rate (“pull rate”). Depending on the process, the viscous glass stream is either continuously shaped or severed into portions of constant weight and shape (“gobs”) which are delivered to a forming machine (container glass).

Compressed air is then used to blow the glass to the required shape. The speed and scale of operation is impressive.

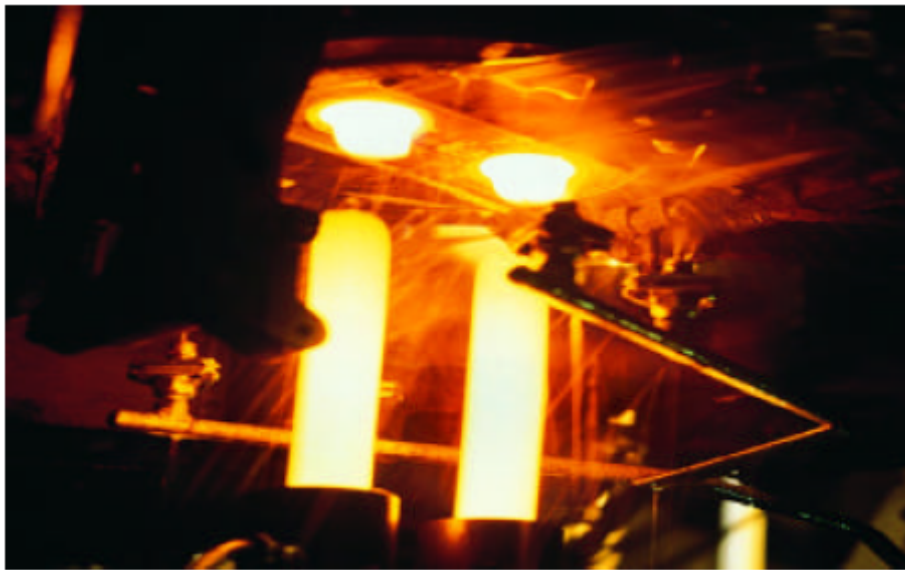


Figure 2.6 Glass "gobs" Fed to Moulds

2.5.4 Production of Container Glass

Container glass is produced by automated processes known as pressing, blowing, press blowing, and blow-blowing. The viscous glass stream leaves the fore hearth through an orifice ring at a constant rate, and is severed into portions of defined weight and shape (“gobs”) by mechanical means. The gobs drop into a chute (“gob feeder”), and are delivered to the forming machine. In simple pressing machines, the gob drops into a preheated mold, and is subsequently pressed into shape by a preheated die. Forming machines for glass bottles pre-shape the gob by either pressing or blowing, and obtain the final shape by injecting air into the gob placed in a surrounding mold. Common is the delivery of multiple gobs at a time to multiple forming stations; typically, the machines are capable of producing 58 containers glass per minute.

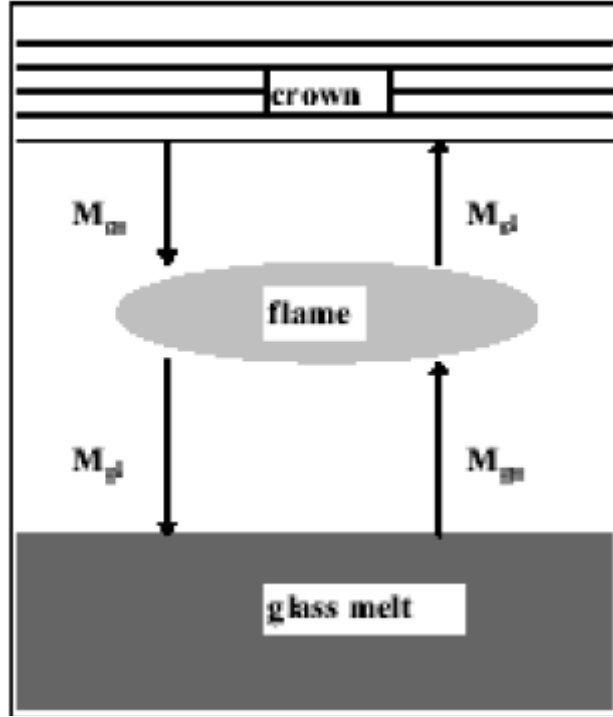
2.5.5 Annealing

The forming process for rigid glass items involves some very rapid temperature changes and induces severe internal stresses within the glassware. These stresses must be removed before the item is safe to handle. The stresses are removed by the process of annealing, which involves reheating the glass followed by a controlled cooling cycle during which the stresses are relieved. The length of the annealing cycle is determined by the thickness of the item and can be of up to 40 minutes in duration. The annealing process is performed continuously with the glassware on a conveyor belt being fed through a long tunnel kiln.

2.6 Heat Transfer

We are also interested in calculating the heat transfer from the flame to the glass melt.

Figure 3.7 shows a simplified representation of the heat exchange within the combustion chamber. The flame radiates heat directly to the glass bath and indirectly radiates to the crown. The radiation exchange is described by the following (simplified) relations:



Figur 2.7 Representation of Heat Exchange in the Furnace

The ε -values are the emission coefficients of the surface of glass melt ($\varepsilon_g = 0.8$), the flame (ε_v) and the crown ($\varepsilon_k = 0.5$), while the temperatures of the same components are shown by the T with the same subscript. The term on the right side of the formula shows the total heat transfer from flame to glass melt [12]. For T_g we take 1773 K and for T_k we assume 1823 K.

$$\text{From the glass bath: } M_u = \varepsilon_g * \sigma * T_g^4 + (1 - \varepsilon_g) * M_i \quad (3.1)$$

$$\text{To the glass bath: } M_i = \varepsilon_v * \sigma * T_v^4 + (1 - \varepsilon_v) * M'_u \quad (3.2)$$

$$\text{From the crown: } M'_i = \varepsilon_k * \sigma * T_k^4 + (1 - \varepsilon_k) * M'_i \quad (3.3)$$

$$\text{To the crown: } M'_i = \varepsilon_v * \sigma * T_v^4 + (1 - \varepsilon_v) * M_u \quad (3.4)$$

Combining equations 3.1, 3.2, 3.3 & 3.4 leads to, the net heat flux from the flame to the glass bath:

$$M_{net} = M_i - M_u \quad (3.5)$$

$$M_{net} = \frac{A * \sigma (T_v^4 - T_g^4) + B * \sigma * (T_k^4 - T_g^4)}{C} \quad (3.6)$$

Where

$$A = \varepsilon_g * \varepsilon_v * (2 - \varepsilon_v - \varepsilon_k + \varepsilon_k * \varepsilon_v)$$

$$B = \varepsilon_g * \varepsilon_k (1 - \varepsilon_v)$$

$$C = 1 - (1 - \varepsilon_v)^2 * (1 - \varepsilon_k) * (1 - \varepsilon_g)$$

M_u = radiation flux from the glass bath (W/m^2)

M_i = radiation flux to the glass bath (W/m^2)

M_u' = radiation flux from the crown (W/m^2)

M_i' = radiation flux to the crown (W/m^2)

M_{NET} = net radiation flux from the flame to the glass bath (W/m^2)

ε_g = emission coefficient of the glass bath

ε_v = emission coefficient of the flame

ε_k = emission coefficient of the crown

σ = constant of Boltzmann ($= 5.67 \times 10^{-8} W/m^2 k^4$)

T_g = glass bath temperature (k)

T_v = flame temperature (k)

T_k = crown temperature (k)

2.7 Electrical Heating

2.7.1 Methods

The melting of container glass is carried out in a continuous process. This can be achieved by electrical heating, using electrodes. There are two options regarding the placement of the electrodes. The first option is direct heating, where the electrodes are placed in the furnace in the glass melt. The second option is the placement of the electrodes outside the glass tank, which is called indirect heating. When electrical heating is used it is possible to heat the furnace:

- ❖ Electrically in combination with another heating method

❖ Pure electrically.

The first alternative, partially electrical heating, involves the heating of the glass melt with electrodes as well as with, for example, conventional burners or radiant tube burners. This way of heating the glass melt is called electrical boosting (used for coloured glass or amber glass).

Using the second alternative, pure electrical heating, the glass is only heated by electrodes.

The glass melt is an ionic conductor. The electrical conduction is mainly provided by the most mobile ions, the alkali metal ions (e.g. Na⁺-ions). A very strong current is conducted through the glass melt, using typically 12-18 electrodes. The resistance of the glass melt causes a Joule's heat dissipation and thus heat is generated in the melt. The voltage applied is an alternating current (AC) voltage. If a direct current is applied, an accumulation of charge around the electrodes will be developed. The electrical charge may also lead to oxidation or reduction of the electrodes and an accelerated attack of the electrode material.

When a glass melt is heated electrically, many different aspects can be considered. The design of the furnace, the type of electrodes (e.g. plates or rods), the position of the electrodes (inside or outside the furnace), the materials used and the number of electrodes can be taken under consideration.

2.7.2 Furnace

In the case of an all-electrically-heated furnace, there is only a slight difference in comparison with the conventional method. Instead of a crown on top of the furnace with the heaters, a cold and flat top is created by covering the glass melt with cold feed. Because there is no combustion process, there are no heat losses from flue gases in the furnace. Furthermore, the heat losses from the holes wherein the electrodes are placed, have to be taken under consideration. During the melting process the holes are insulated but the electrodes are cooled with water. The heat losses due to this water cooling of the electrodes depend on the thickness of the electrodes.

2.7.3 Electrodes

The type of electrodes used in an all-electrically-heated furnace is of great importance. Besides the high costs of electricity, one of the problems with direct heating may be the discolouration of the glass melt by the electrodes. This discolouration may be caused by the attack of the electrodes by the glass (formation of oxides with colouring power) and by the formation of bubbles. The bubbles are formed during several transformations that take place during heating

and melting. A large amount of gases are formed, for example CO₂ and SO₂. The amount of oxides (originating from the electrodes) in the glass melt depends on the following factors:

- **Temperature**

The attack of glass on the electrodes increases with increasing temperature. A possible solution could be the cooling of the electrodes.

- **Area of contact surface**

The amount of dissolved oxides is proportional to the contact area of the electrodes.

- **Current density**

The current density should be low at the place where the electric current goes from the electrodes into the glass melt. At this place electrolytic action is concentrated and the attack is less when the current density is lower.

- **Chemical composition of the glass**

The chemical composition of the glass determines the oxidation number of the glass melt. This oxidation number determines the oxidation rate of the glass and thus influences the amount of attack on the electrodes and the discolouration of the glass. These factors are contradicting because when a small electrode is used, there is a small surface contact area and this results in a high current density. Joule's law ($P = I^2 \cdot R$) shows that the heat development is proportional to the square of the current strength and therefore the electrode will also have a high temperature. In what way the discolouration will take place, also depends on the contact time between the electrode and the glass melt. Shorter time of contact between the melt and the electrodes means less attack and less solution of oxides and thus less colouring effect. To achieve a shorter contact time, thorough mixing is needed. This results in the dilution of the colouring oxides. The colouring oxides are then distributed in a larger volume of the glass melt. When mixing is involved, the convection current becomes important. It starts at the hotspot near the electrode, raises the speed of flow and thus decreases the contact time of the glass melt and the electrode. The shape of the convection current strongly depends on the arrangement of the rod-shaped electrodes in the electrical melting tank.

When the electrodes are placed horizontally (figure 3), the electrodes cause a certain convection pattern that sets up a thermal dam. This dam retards the forward stream of the glass along the tank. Much more favorable is the situation where the electrodes are placed vertically through the bottom of the tank (figure 4), because in this case the hot glass melt can rise free and unhindered

to the surface. This improves the convection current, which results in better mixing, homogenizing and good decolourising. Because of the vertical placement of the electrodes, the upward movement of the intensely heated glass near the electrodes is accelerated and the danger of overheating the glass near the electrodes is also limited. The type of materials used for the electrodes is important. For direct heating usually electrodes of molybdenum are used. The heating part of the electrodes is fully placed in the glass melt to prevent the electrodes from oxidation by air. When the furnace is heated electrically in an indirect way other materials have to be used such as Kanthal super elements. Kanthal super elements comprise of molybdenum disilicide and a component that forms a dense protective layer of quartz glass around it at the working temperature. This electrical heating

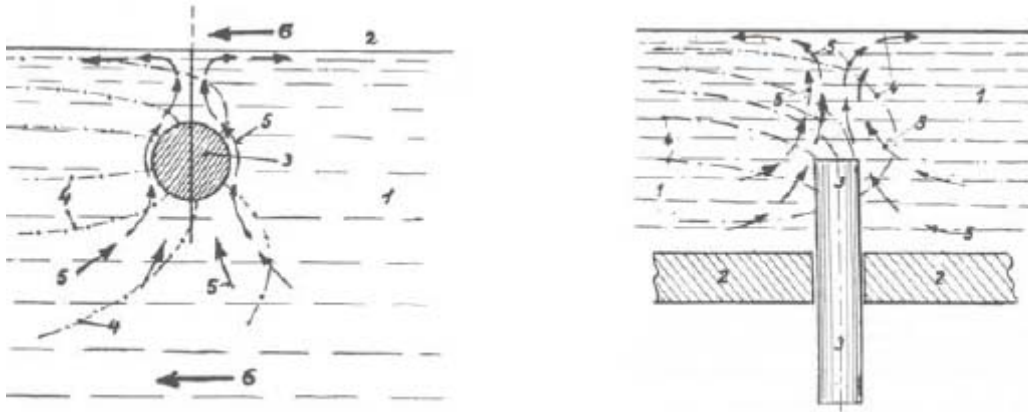


Figure 2.8 Side Wall Horizontally & Side Bottom Vertically Placed Electrode

element can be used at high surface loadings and can be arranged in groups to give wall loadings higher than 100kW/m^2 .

CHAPTER 3

3 ENERGY BILL ANALYSIS

3.1 Introduction

The company consumes both thermal energy and electric energy for container glass production. The company pays for both thermal energy and electric energy. For the 2000/01 (E.C) fiscal year the amount of energy bill paid by the company were 2,028,547.2 Birr and 4,774,275.78 Birr for the furnace oil and electricity respectively.

The company consumes both furnace oil and electricity in order to operate its major energy consuming systems. For example electricity is consumed to operate motor, pump and fans in the plant and also, to operate different machineries in the plant machine shop. A small amount of electricity is also used to lighting purpose. In addition to electricity, however, the core function of turning the batch into final container glass production.

To analyze company energy bill the 12-month energy (furnace oil and electric), raw material and container glass data are collected. In addition to this, energy intensity data of factories overseas (benchmark) are considered for comparison. These collected data are presented below.

3.2 Data Gathering

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

3.2.1 Company Energy Consumption Data

In the past 12-month from Sep 2001 to Aug, 2001E.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 container glass production data, were collected from company logbook. The data is presented in appendixes A.

3.2.2 Energy Consumption of Benchmark Countries[24]

Figures 4.1 and 4.2 provide the four years (1991, 1994, 1998 & 2002 G.C) fuel oil and electricity energy intensity consumption pattern of the benchmark i.e. India, USA, and Ukraine. The energy intensity consumption in these countries is an average in industries at national level.

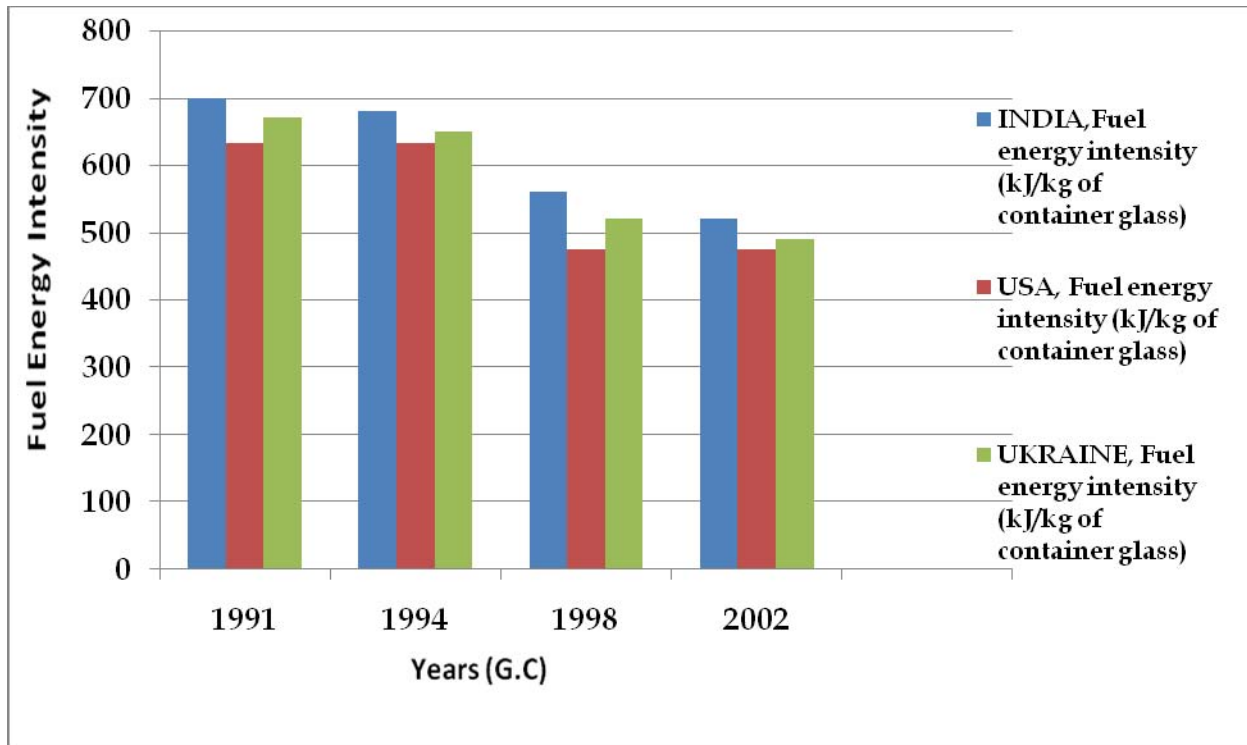


Figure 3.1 Fuel Oil Energy Intensity of the Benchmark Countries

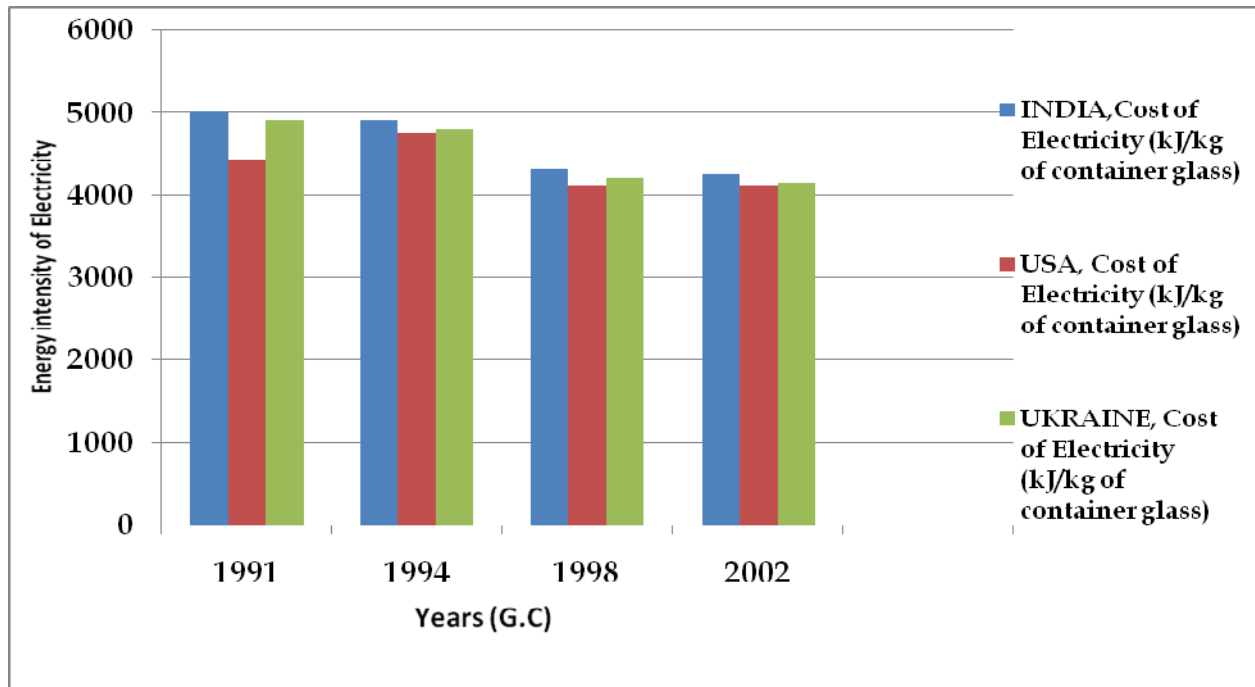


Figure 3.2 Electricity Energy Intensity of the Benchmark Countries

3.3 Data Analysis

The collected data is processed in to monthly company paid for furnace oil and electricity consumption and monthly fuel and electricity energy intensity consumption pattern.

3.3.1 Monthly Energy Cost of the Company

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 0.92 and 4.187×10^4 kJ/kg respectively. The price is taken as 9.49 birr/litre according to Ethiopian petroleum agency price. Billing for electricity is varying according to voltage consumption and number of phase used in the company. The company uses 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 0.5778 birr/kWh. Monthly furnace oil and electricity cost are given by equation 4.1 and 4.2 respectively.

$$MFC = 9.49 \frac{\text{Birr}}{\text{Litre}} * \text{monthly fuel used in liter} \quad (3.1)$$

Where

MFC - Monthly fuel cost in [Birr/month]

$$MEC = 0.5778 \frac{\text{Birr}}{\text{kWh}} * \text{monthly electric used in kWh} \quad (3.2)$$

Where

MEC - Monthly electricity cost

Using appendix A data and substituting in equation (4.1) & (4.2), the monthly company fuel and electricity costs are tabulated in table 4.1. The following table 4.1 and fig. 4.3 provides monthly energy cost for fuel and electricity consumption.

Table 3.1 Monthly Fuels & Electricity Cost at AABGSC

Billing Period (E.C)	Cost of Fuel (Birr)	Cost of Electricity (Birr)	Total cost (Birr)
Sep-01		433,987.21	433,987.21
Oct-01		331,965.16	331,965.16
Nov-01		425,406.61	425,406.61

Dec-01		382,503.61	382,503.61
Jan-01		332,245.81	332,245.81
Feb-01		451,148.41	451,148.41
Mar-01		373,923.01	373,923.01
Apr-01		346,955.41	346,955.41
May-01		471,987.01	471,987.01
Jun-01			
Jyl-01	155,157.12	467,083.81	622,240.93
Aug-01	13,888.48	359,213.41	373,101.89
Total	2,028,547.2	4,376,419.46	6,404,966.66

3.3.2 Monthly Energy Intensity Consumption Pattern of the Company

Monthly energy intensity consumption is defined as an average monthly energy needed to produce one kilogram of container glass.

Monthly fuel and electricity energy intensity given by equation 4.3 and 4.4 respectively

$$MFEI = \frac{GCV * \rho_{Fuel} * monthly\ fuel\ used(litre)}{monthly\ container\ glass - produced} \quad (3.3)$$

where

MFEI – Monthly fuel energy intensity

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

ρ_{Fuel} – Density of fuel kg/Lit

$$MEEI = \frac{monthly\ electricity\ used(kWh) * 3600\ sec}{monthly\ container \dots glass\ produced} \quad (3.4)$$

where

MEEI – Monthly electric energy intensity

Using appendix A data and substitute in Equation (3.3) & (3.4) the monthly company fuel energy intensity and electricity energy intensity is tabulated in Table 3.2. The following table 3.2 and fig. 3.4 & 3.5 provide monthly fuel and electricity energy intensity.

Table 3.2 Monthly Energy Intensity of Fuel & Electricity

Billing Period (E.C)	Energy intensity of Fuel (kJ/kilo gram of container glass)	Energy intensity of Electricity (kJ/ kilo gram of container glass)
Sep-01		5,021.49
Oct-01		4,064.89
Nov-01		4,056.31
Dec-01		3,776.02
Jan-01		4,037.42
Feb-01		7,233.57
Mar-01		3,936.57
Apr-01		3,316.89
May-01		6,525.24
Jun-01		
Jyl-01	1080.67	4993.62
Aug-01	96.75	3,840.96
Mean	588.71	4618.45

3.4 Analysis of the Energy Utilization of the Company

As is clearly seen in Figures 4.4 and 4.5 the energy utilization pattern of the company considerably varies over the whole fiscal year, 2000/01 E.C. Electric energy intensity during the month of February appear to have increased significantly as compared with other months. For instant the energy intensity consumption of the month February is 7,233.573kJ/Kg. These indicate that the energy efficiency of the furnace with time has dropped considerably. Thus the furnace is one of the main energy consuming systems of the company that must be investigated in detail.

3.5 Energy Intensity Comparison of Company with Benchmark

The comparison is made between energy intensity of Addis Ababa Bottle & Glass Share Company (AABGSC) and the benchmark. From the analysis of the energy intensity of the

AABGSC it can be seen that there is a significant difference between the energy intensity of the AABGSC as compared to the benchmark.

The fuel energy intensity of AABGSC an average energy intensity of 588.71 kJ/kg of container glass. The energy intensity of benchmark, for example USA showed in fig 3.1 gives in 2002(G.C) average energy intensity of 474.75 kJ/kg of container glass.

With regards to electricity energy intensity of AABGSC an average intensity of 4618.45KJ/Kg of container glass. The energy intensity of the benchmark for example USA showed in fig 3.2 gives an average energy intensity of 4114.5kJ/kg of container glass.

3.5.1 AABGSC Cost Comparison with Benchmark

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

Important Data

1. AABGSC Production in 2000/01 E.C = 6,008,685Kg of container glass [Table3.1]
2. Cost of fuel oil = 9.49birr / lit
3. Cost of electricity = 0.5778birr /kWh flat rate
4. Specific heat of fuel oil = 41,423.8 kJ/Lit
5. Difference in electricity energy intensity = 0.14wh/ kg of container glass
6. Difference in fuel energy intensity = 113.96 kJ/kg of container glass

Difference in annual energy cost due to lower efficiency use of fuel and electricity are obtained using equation (3.5) and (3.6) for fuel and electricity respectively.

Annual cost due to low electricity utilization of the company is given by equation (3.5)

$$AC_{Ele} = DEI_{Ele} * CAPC * CE \quad (3.5)$$

Where

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

DEI_{Ele} – Difference of electricity energy intensity

$CAPC$ – Company annual production capacity

CE – Cost of electricity in Birr

Substituting the above value from the data in equation (3.5) annual energy cost due to lower electricity energy intensity of the company is given by

$$AC_{Ele} = 0.14 \frac{kWh}{Kg_{co...Glass}} * 6,008,685 \frac{Kg_{co...Glass}}{Year} * 0.5778 \frac{Birr}{kWh}$$

$$= 486,054.55 \text{Birr/ year}$$

$$AC_{Fuel} = \frac{DEI_{Fuel} * CAPC * CF}{HHV} \quad (3.6)$$

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

DEI_{Fuel} – Difference of fuel energy intensity

$CAPC$ – Company annual production capacity

CF – Cost of fuel in Birr

HHV – Higher Heating Value of furnace oil in kJ/lit

Substituting the above value from the data in equation (3.6) annual energy cost due to lower efficiency of fuel of the factory is given by

$$AC_{Fuel} = \frac{113.96 \frac{kJ}{kg_{bar}} * 6,008,685 \frac{kg_{con...gl}}{Year} * 9.49 \frac{Birr}{Lit_{Fuel}}}{41,423.8 \frac{kJ}{Lit_{Fuel}}}$$

$$AC_{Fuel} = 156,872.98 \text{ Birr/ year}$$

Therefore

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

$$AEC = AC_{Fuel} + AC_{Ele} \quad (3.7)$$

Substitute equation (3.5) and (3.6) in (3.7) the total difference is the annual cost due to lower efficiency of energy utilization of the company

$$= 642,927.53 \text{ Birr/ year}$$

3.6 Concluding Remark on the Energy Intensity Comparison

Based on the above analysis, we can state that the AABGSC energy utilization system is inefficient and more costly as compared to the benchmark. This is mainly due to energy mismanagement and lack of attention to energy wastage during the production process. The

losses incurred by the company greatly reduce its profits. Hence the company must conduct energy audit on its major energy systems.

CHAPTER 4

4 PRELIMINARY ENERGY AUDIT OF THE COMPANY

4.1 Introduction

The preliminary energy audit of the company is performed through inspection of the eight general energy systems: the building envelop, furnace, the heating ventilating and air conditioning systems (HVAC), the electric supply systems, the lighting systems, the compressed air distribution systems, the motor and manufacturing systems using visual inspection, common sense and interview with company workers in order to identify energy conservation opportunities (ECOs) and identify the major energy systems of the company so as to perform the detail energy audit of the major systems. These preliminary audits inspections are discussed below.

4.2 Inspection of the Company Buildings Envelope

The company buildings envelope is inspected visually. The buildings are made of brick walls. The roofing of all buildings in the company is made of corrugated iron sheet. The physical condition of the building is good but requires some maintenance like changing old corrugated iron sheet roof with new one. From the energy stand view the current condition of the building is satisfactory. Moreover the building is not air-conditioned and hence no attempt is made to inspect the building envelope in the light of energy conservation opportunity assessment.

4.3 Inspection of the Melting Furnace

The furnace used in the company is constructed by an English Company. The systems included in the furnace are: feed raw material system, combustion air system and fuel system. The feed raw material system provides raw material to the melting furnace and regulates its temperature automatically to produce the specified capacity of container glass in the melting furnace. The fuel system includes all equipment used to provide fuel to generate the heat. The melting furnace use both furnace oil and electricity.

Inspection of the melting furnace and container glass distribution system is conducted using visual inspection, common sense and interview with company workers and revealed the following energy conservation opportunities.

4.3.1 List of ECOs Identified

The various energy efficiency opportunities in furnace and container glass systems can be related to combustion, heat transfer & avoidable losses, are inspected and discovered the following list of ECOs.

- 1) No proper burner adjustments.
- 2) External body of the furnace is high temperature.
- 3) The furnace is without a recuperator heat exchanger.
- 4) High heat losses in between the chimney and the melting furnace.

The ECOs listed from number 1 - 2 above are simple to be implemented with the routine maintenance program of the company, with no, or low cost. But the ECOs listed as numbers 3 & 4 need further data collection and entail conducting detail energy audit of the furnace.

4.4 Inspection of the HVAC System

The HVAC system of the company is composed of few ventilations system. There is no any air conditioning system in the company office building as well as in the production shop. Ventilator do not exists in the production shop and hence no attempt is made to check energy conservation opportunities.

4.5 Inspection of the Electric Supply system of the Company

The electric supply system of the company consists of transformer, wiring, switches and fuses. The transformer is used to step down the voltage from 15-kilo volt to three-phase 380v and two-phase 220v. The authorized organization to inspect the company transformer is Ethiopian Electric Power Corporation. There is no attempt made to check energy conservation opportunities.

4.5.1 List of ECOs Identified

The inspection of the company electric supply system has shown the following list of ECOs:

1. The transformer fins are dirty.
2. Install power measuring instrument for each electric appliance systems.

Maintaining the proper cooling system of the transformer, cleaning the fins dirt around the transformer is important and can be done by the routine maintenance program of the company. The company can deserve no cost but the company is purchasing normal electric power measuring meters.

4.6 Inspection of the Lighting System

Lighting is not always the biggest energy consumer in the glass manufacturing processes but it is usually one of the best opportunities for reducing energy costs. And, as a bonus, most lighting upgrades also result in improved lighting quality. Often significant energy savings can be realized with a minimal investment of capital and common sense.

The high energy intensity of the glass manufacturing processes, energy use for lighting is comparatively small. The lighting systems of the company shops are composed of few fluorescent and incandescent lamps. This system was inspected visually to find energy conservation opportunities (ECOs).

4.6.1 Lists of ECOs Identified

The lighting system of the company the following ECOs are obtained from the visual inspection.

1. Not installed lighting control system
2. Some of the company lamps (fluorescent) are placed high level.
3. Most of the incandescent lamps are dirty.
4. Some of the company lamps are old incandescent.

Replacing mercury vapor or incandescent sources with metal halide or high pressure sodium will generally result in reduced energy costs and increased visibility. Installing and maintaining photo-controls, time clocks, and energy management systems can also achieve extraordinary savings. However, in some cases it may be necessary to consider modifications of the lighting design in order to achieve the desired energy savings. It is important to understand that efficient lamps alone would not ensure efficient lighting systems.

4.7 Inspection of the Compressed Air Distribution System

Compressed air is an essential power source for the company. It is a safe operation, relatively inexpensive to operate and very reliable. However, compressed air is susceptible to various types of contamination which not only reduces its value as a power source, but can seriously affect the performance of other pneumatic equipment and, therefore, productivity.

Compressed air may be used throughout the company, but is mostly used in the forming of containers. The company used piston type double stage and air-cooled compressor. The inspection of compressor and compressed air distribution system is conducted using visual inspection.

The company air compressor and compressed air distribution system is used to performing the pneumatic operation of the forming machine, operate pneumatic valve and dust remover.

4.8 Inspection of the Motor Systems

Motors are used throughout glass manufacturing plants in compressed air systems, cooling water pumps, furnace air blowers, ventilation fans, as well as for transport (conveyors).

There are over 16 three phase motors in the company floor in order to operate pumps, fans and air compressor that operate in the range of 820 hr to 4800 hr per 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.

4.8.1 Lists of ECOs Identified

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

- 1) No systems approach
- 2) Not ongoing motors maintenance
- 3) Most of the electric motors are exposed to dirt.
- 4) Most of the motors are old (installed when the company was built)
- 5) The nameplate power factor ranges from 0.80% to 0.86%.
- 6) Nameplate efficiency of the motors is ranges (0.75% - 0.85%).

The ECOs listed in number 1 up to 3 above are simple to be implemented with the routine maintenance program of the company with no cost. But the ECOs listed from number 4 up to 6 need further data collection and entails conducting detail energy audit of the motors with its prime movers.

4.9 Inspection of the Manufacturing Systems

The manufacturing systems of the company intensively utilized thermal and electric energy. All the thermal energy is consumed by the melting process. The electric energy is mainly for hearth, Lehr, pumps, air compressor and fans.

Melting is one of the most energy intensive operations in the company. It is used throughout container glass producing processes.

Inspection of manufacturing system means inspection of melting furnace because it consumes all thermal & electrical energy produced by the furnace.

4.9.1 Lists of ECOs Identified

The melting furnace system of the company was assessed for potential ECOs and the following were obtained.

1. For long time the pressure sensing measuring instruments of the oil pipe system is not calibrated.

2. Large quantity of heat is lost through the furnace wall.

ECOs 1 from the above lists of technically feasible ECOs are low cost or no cost energy conservation opportunities sorts that can be handled with the routine maintenance and job of the company. ECOs number 2 required further data collection.

4.10 Identification of the Major Energy Systems of the Company

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

- Melting furnace
- Fore hearth
- Lehr
- Electric motors and its prime movers

The energy production from furnace oil, goes to the furnace. And the total energy supplied from electric power, almost 80% goes to furnace, fore hearth & motors. Saving energy in glass company would an improving combustion efficiency of the furnace and motors efficiency. Therefore the detail energy audit of these major energy systems of the company can be performed through assessment of their energy performance according to the following categories in the separate chapter.

- Thermal energy audit of:
 - Melting furnace
- Electric energy audit of:
 - Motors and its prime movers
 - Fore hearth
 - Furnace

CHAPTER 5

5 DETAILED ENERGY AUDIT OF THE MELTING FURNACE

5.1 Introduction

The major thermal energy source of the company is furnace. The main function of the melting furnace is to melt the batch. In order to perform the energy accountings and thus energy balances and determine the efficiency of the furnace the following data/measurements are required.

- ❖ Dimension and surface temperature of the furnace
- ❖ Batch feeding rate and temperature
- ❖ Internal temperature of the melting furnace
- ❖ Fuel oil flow rate and pre-heating temperature
- ❖ Exit flue gas temperature and percentage of combustion products constituents
- ❖ Melting discharging temperature
- ❖ Ambient temperature

These different data related to energy utilization and development of the furnace mentioned above were collected by

- Direct measurement using portable instruments
- Directly recording from company furnace control panel
- Referring different company record book and log sheets and
- Interview with company workers

5.2 Collected Data for Conducting Detail Energy Audit of the Furnace

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

5.2.1 Flue Gas Analysis

Combustion analysis is part of a process intended to improve fuel economy, reduce undesirable exhaust emissions and improve the safety of fuel burning equipment. Combustion analysis begins with the measurement of flue gas concentrations and gas temperature, and may include the measurement of draft pressure and soot level. To measure gas concentration, a probe is inserted into the exhaust flue and a gas sample drawn out. Exhaust gas temperature is measured using a thermocouple positioned to measure the highest exhaust gas temperature. Soot is

measured from a gas sample drawn off the exhaust flue. Draft is the differential pressure between the inside and outside of the exhaust flue. Once these measurements are made, the data is interpreted using calculated combustion parameters such as **combustion efficiency** and **excess air**[10].

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, and 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 and these data are presented in Table 6.1.

Table 5.1 Measured Flue Gas Data

	Reading	Data collection methods
O ₂ in flue gas [%]	12.1	Measured
Stack temperature[⁰ C]	726	Measured
Ambient temperature[⁰ C]	32	Measured
CO ₂ [%]	6.6	Measured
CO [ppm]	0	Measured
Free stream air composition		
Nitrogen 79%	Oxygen 21%	

5.2.2 Melting Furnace Surface Loss Analysis

To estimate the energy lost from the furnace surfaces, surface temperatures of the furnace that are exposed to the ambient are measured at different location using an infrared and dual K contact thermometer. The furnace is of hexagonal shape and surfaces that are exposed to the ambient are: top surface, bottom surface and the six side surface. In addition to furnace surface temperature, batch feed temperature and molten glass outlet temperatures are measured. The average temperatures of the furnace surface exposed to the ambient and fuel preheating temperature are described in Table 5.2.

Table 5.2 Measured Furnace Temperature

No	Measured side	Surface temp. °C	Ambient temp. °C
1	A	292	37
2	B	273	36
3	C	179	31.5
4	D	172	31
5	E	210	34
6	F	224	35.5
7	Top	160	31
8	Bottom	257	36
9	Fuel pre-heating Temperature = 80°C		
10	Molten glass produced at a temp. 1070 °C		
11	Water cooling an electrode at a temp. 48°C		
12	Length = 2m and height = 1.375m		

5.2.3 Furnace Dimensions Analysis

The Vernier's calliper was used to measure the internal pipe diameters of fuel oil pipe, which is 0.265m. The total area of the molten glass on the log sheet is 16m².

5.3 Pre-Audit Energy and Mass Balance Analysis

In order to perform the detailed energy audit of the furnace the following pre-audit input-output energy and mass balance analysis listed here under must be performed.

- ✓ Heating value of furnace oil
- ✓ Analysis of furnace oil combustion
- ✓ Analysis of mass flow rate of fuel
- ✓ Electrical consumption of the furnace

5.3.1 Heating Value of Furnace Oil

The company uses furnace oil as fuel source to produce container glass. The heating values of furnace oil are important to determine the input energy in to the melting furnace. The gross calorific value of furnace oil (GCV) is dependent on the physical composition of furnace oil.

From reference [8] the composition and gross calorific values (GCV) of furnace oil is presented in Table 5.3.

Table 5.3 Composition of Furnace Oil & Ultimate Analysis

Composition of Furnace oil	Symbol	Ultimate Analysis in %
Carbon	C	84
Hydrogen	H	12
Oxygen	O ₂	1.5
Sulphur	S	1.5
Nitrogen	N ₂	0.5
Moisture	M	0.5
Gross Calorific Value = 41,800kJ/kg		

The net calorific value 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) we can estimate the net calorific value of furnace oil.

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

Where

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

(M_{H_2O}) - Mass of water vapour in the flue gas due to combustion of hydrogen and moisture content of fuel

But

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

Where: - 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) become

$$(M_{H_2O}) = 9 \times 0.12(1 - 0.5) + 0.5 = 1.04 \quad (6.3)$$

Substitute the values of (6.3), GCV and h_{fg} NCV in (6.1) become

$$\begin{aligned} NCV &= 41,800 \text{kJ/kg} - (1.04 \times 2441.12 \text{kJ/kg}) \\ &= \mathbf{39261.23 \text{kJ/kg}} \end{aligned}$$

5.3.2 Analysis of Furnace Oil Combustion

In order 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

5.3.3 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°C and $P_a=77\text{kPa}$. The average relative humidity of the air used for combustion is $\phi = 53.25\%$ [16]. 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.

1) 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 28°C . The humidity factor of the air is given by[38]

$$\text{Humidity} \dots \text{factor}(\gamma_A) = 0.62198 \frac{P_w}{P_a - P_w} \quad (6.4)$$

Where

P_w - partial pressure of water vapour in moist air

P_a - atmospheric pressure of moist air

But the value of the partial pressure of the water,

$P_v = \phi P_{sat \dots \text{at} \dots 28^{\circ}\text{C}} = 53.25\% P_{sat}$ From steam table at 28°C the value of the saturation pressure,
 $P_{sat} = 3.803\text{kPa}$ hence $P_v = 53.25\% * 3.803 = 2.0251\text{kPa}$

Therefore, humidity factor (γ_A) = $0.62198 \frac{2.0251}{77 - 2.0251} = 0.0168 \frac{\text{Kg} \dots \text{of} \dots \text{H}_2\text{O}}{\text{Kg} \dots \text{of} \dots \text{air}}$

2) 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 so as to handle the mass balance of the constituents relative to oxygen and this is done in Table 6.5

5.3.4 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.

Table 5.4 Mass Analysis of Dry & 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	0.2069	32.00	6.72	6.62	0.23	1
N ₂	0.79	0.7786	28.00	22.12	21.80	0.76	3.763
H ₂ O	-	0.01434	18.00	0.00	0.258	0.00899	0.0693
Sum	1.00	1.00		28.84	28.678		

1) Theoretical Air-Fuel Ratio (TA)

To determine the theoretical air-fuel ratio of furnace oil burning 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 [8]. The percentage of fuel constituents is presented in Table 6.4

$$\begin{aligned}
 \text{TA} &= [(11.6 \times \text{C}) + \{34.8 \times (\text{H}_2 - \text{O}_2/8)\} + (4.35 \times \text{S})]/100 \text{ kg/kg of fuel oil} \\
 &= [(11.6 \times 84) + \{34.8 \times (11.8)\} + (4.35 \times 1.5)]/100 \text{ kg/kg of fuel oil} \\
 &= 13.92 \text{ kg of air/kg of oil} \qquad \qquad \qquad (6.5)
 \end{aligned}$$

2) Actual Air - Fuel Ratio of Furnace Oil (AA)

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

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

Where

EA - excess air supplied

TA - theoretical amount of air fuel ratio

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

Excess Air Supplied (EA)

The excess air supplied to the furnace can be computed from the oxygen percent of the flue gas composition of table 6.1 using formula (6.7).

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

% O_2 measured in flue gas = 12.1 % and substitute in (6.7) the excess air is:

$$\begin{aligned} EA &= \frac{12.1}{21 - 12.1} \times 100 \\ &= 136 \% \end{aligned} \quad (6.8)$$

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

$$\begin{aligned} AA &= [1 + 136/100] \times [13.92] \\ &= 32.85 \text{ kg of air / kg of fuel} \end{aligned}$$

5.3.5 Mass Flow Rate Analysis of Dry Flue Gases

When fuels burn, oxygen combines with chemical components of the fuel and releases energy in the form of heat. Because there are many components in fuel, there are many chemical reactions associated with combustion.

In order to calculate the energy losses due to flue gases (stack loss) the mass flow rate of the flue gases must be determined. In order to find the mass flow rate of the dry flue gases the composition of the gas products of the actual chemical reaction in the furnace must be determined first.

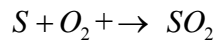
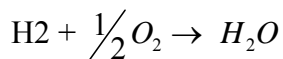
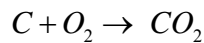
Table 5.5 Molecular Weight of the Constituents of the Fuel

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

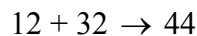
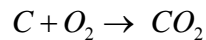
The combustible elements in furnace oil are carbon, hydrogen and sulphur. During burning of furnace oil with dry air these three elements give carbon dioxide, water and sulphur dioxide. Therefore the standard chemical reaction of furnace oil burning the oxidation of 1kg of furnace oil completely in to carbon dioxide, water and sulphur dioxide with inert nitrogen in the product stream using dry air which is given by

1kg of furnace oil + Dry air → Carbon dioxide + Water + Sulphur dioxide + inert Nitrogen

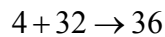
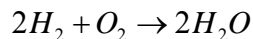
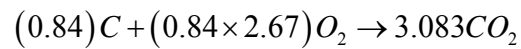
Mathematically as follow:



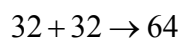
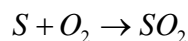
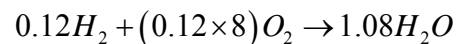
Constituents of fuel



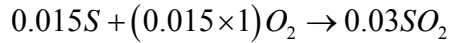
12 kg of carbon requires 32 kg of oxygen to form 44 kg of carbon dioxide therefore 1 kg of carbon requires 32/12 kg. i.e. 2.67 kg of oxygen.



4 kg of hydrogen requires 32 kg of oxygen to form 36 kg of water, therefore 1 kg of hydrogen requires 32/4 kg i.e.8 kg of oxygen



32 kg of sulphur requires 32 kg of oxygen to form 64 kg of sulphur dioxide, therefore 1 kg of sulphur requires 32/32 kg i.e. 1 kg of oxygen



Excess air quantity = Actual air supplied - Theoretical air required

$$= 32.85 \text{ kg} - 13.92 \text{ kg}$$

$$= 18.93 \text{ kg of air}$$

$$\text{Excess } O_2 = 18.93 \text{ kg} \times 0.23 (\text{by mass}) = 4.35 \text{ kg}$$

$$\text{Excess } N_2 = 18.93 \text{ kg} \times 0.77 (\text{by mass}) = 14.57 \text{ kg}$$

The final constitutions of flue gas with 136% excess air for every 1 kg fuel is the summation of the constitution list below.

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

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

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

$$O_2 = 4.35 \text{ kg / kg of fuel}$$

$$N_2 = 14.57 \text{ kg} + 10.72 \text{ kg} = 25.29 \text{ kg / kg of fuel}$$

Therefore total mass of flue gas (m) = 33.8 kg flue/ kg fuel (6.9)

Multiplied (6.9) with mass flow rate of furnace oil (6.3) the mass flow rate of flue gases is

(\dot{m}_{flue}) is:

$$\begin{aligned} \dot{m}_{flue} &= 33.8 \frac{\text{kg}_{flue}}{\text{kg}_{fuel}} \times 0.145 \frac{\text{kg}_{fuel}}{\text{sec}} \\ &= 4.91 \frac{\text{kg}_{flue}}{\text{sec}} \end{aligned} \quad (6.10)$$

5.3.6 Specific Heat of Dry Flue Gases

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

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

Where

$$T_{furnace} - \text{Furnace temperature}$$

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

$$C_{P_{fg}} = (0.3 + 0.000038 \times 1345) \text{ kcal / kg } ^\circ\text{C}$$

$$C_{p_{fg}} = 0.351 \text{ kcal} / \text{kg}^\circ \text{C}$$

$$1 \text{ kcal} / \text{kg}^\circ \text{C} = 4.187 \text{ kJ} / \text{kgk}$$

5.3.7 Analysis of Mass Flow Rate of the Furnace

In order to calculate the furnace input output energy the mass flow rate of furnace oil, combustion air & feeding batch must be determined.

5.3.8 Analysis of Mass Flow Rate of Furnace Oil

The company use furnace oil as fuel source to produce molten glass. The mass flow rate of furnace oil is important to determine the input energy in to the furnace. The mass flow rate can be determined direct multiplying of fuel flow velocity, area of the pipe fuel flow and the density of fuel. The measured velocity, pipe diameter and density are recorded 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.

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

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

Where

A_f - Area of fuel flow pipe

V_f - Velocity of fuel flow = 0.0511 $\frac{\text{m}}{\text{s}}$

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

D - Diameter of pipe = 0.0265 m

Substitute the above data in equation (6.12) the area of fuel flow pipe:

$$A_f = \frac{\pi D^2}{4} = (3.14 * (0.0265)^2) / 4 = 0.005513 \text{ m}^2$$

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

$$\dot{m}_f = V_f \times A_f \times \rho_f = 0.0342 \frac{m}{s} * 0.005513 m^2 * 991 \frac{kg}{m^3} = 0.186 \frac{kg}{s} \quad (6.13)$$

5.3.9 Analysis of Mass Flow Rate of Feed Batch

The inlet batch temperature is at ambient temperature. Since the enthalpy of the surrounding air temperature is calculated relative to the temperature of the entering batch, the relative enthalpy of batch is zero.

5.4 Energy Analysis of the Melting Furnace

To perform the thermal energy audit of the melting furnace and to obtain the first law combustion and melting furnace efficiency thermal energy analysis of the melting furnace must be conducted. The energy analysis is done based on the energy input and output of the melting furnace. All the input-output energy of the melting furnace is as shown in fig 6.1.

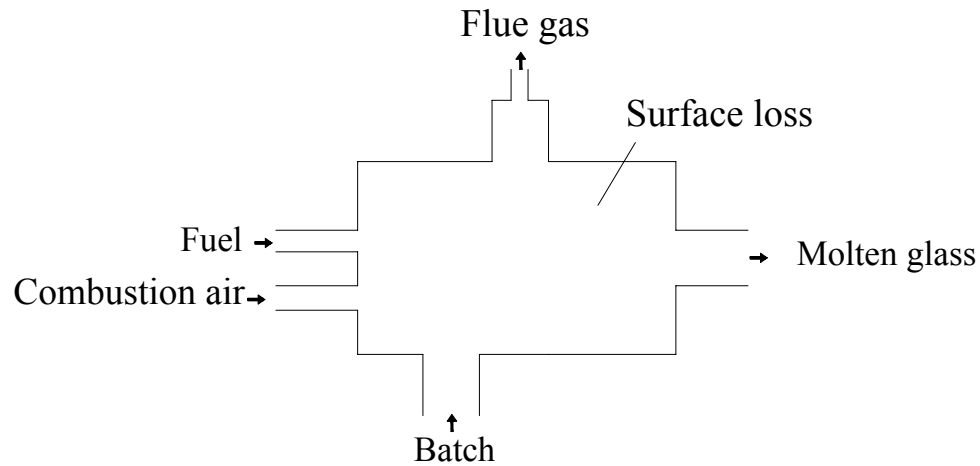


Figure 5.1 Input-Output of the Melting Furnace

5.4.1 Analysis of the Input Energy in the Melting Furnace

As described in fig.6.1 furnace oil, furnace oil due to its pre-heating combustion air are the input energy of the melting furnace. Each input energy source of the melting furnace is discussed below.

Furnace Oil Energy

As illustrated in [6] the furnace oil contains chemical energy converted into heat by virtue of its chemical constituents and pre-heating of the fuel at inlet to the furnace respectively.

1) Chemical Energy of Melting Furnace Oil

The chemical energy of the furnace oil is its heating value. To calculate the energy efficiency of the melting furnace 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 6.3 and equation (6.11) described the GCV and mass flow rate of the furnace oil respectively; therefore the chemical energy of the fuel can be obtained by using equation (6.14).

$$Q_f = m_f (GCV) \quad (6.14)$$

Where: Q_f - Chemical energy of the fuel

m_f - Mass flow rate of the fuel

$$GCV - \text{Gross caloric value of the fuel} = 41,800 \frac{kJ}{kg}$$

Substitute the above data in (6.14) the chemical energy of the fuel is

$$Q_f = m_f (GCV)$$

$$Q_f = 0.186 \frac{kg}{s} \times 41,800 \frac{kJ}{kg}$$

$$Q_f = 7774.8 \text{ kW}$$

2) Energy due to Fuel Pre-Heating

The preheating temperature of a material is the product of the mass, the change in temperature and the specific heat. i.e. Energy = Mass x Specific Heat x rise in temperature. The specific heat of the material can be obtained from a reference manual and describes the amount of energy required by different materials to raise a unit of weight through one degree of temperature. The energy due to fuel pre-heating is the enthalpy of furnace oil by 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 equation.
(6.15)

$$Q_{f1} = \dot{m}_f \times C_f \times (T_f - T_a) \quad (6.15)$$

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

$$C_f - \text{Specific heat of fuel} = 1.003 \frac{\text{kJ}}{\text{kg}^\circ\text{K}}$$

$$T_f - \text{Fuel pre-heating temp.} = 80^\circ\text{C} \text{ [Table 6.2]}$$

$$T_a - \text{Ambient temp.} = 32.5^\circ\text{C} \text{ [Table 6.1]}$$

Substitute the above data in (6.15) the energy content of the fuel due to its pre heating becomes:

$$Q_{f1} = 0.189 \frac{\text{kg}}{\text{s}} * 1.003 \frac{\text{kJ}}{\text{kg}^\circ\text{K}} (80^\circ\text{C} - 32.5^\circ\text{C})$$

$$Q_{f1} = 9 \text{ kW}$$

5.4.2 Analysis of Electrical Energy

Table 5.6 The Panel Reading of Voltage & Current

	Voltage in volt	Current in ampere
Phase A	162	2250
Phase B	167	2282
Phase C	164	2251

$$P = V * I \quad (6.16)$$

Where

P is power in watt

V is voltage

I is current

$$P_A = I^2 R \dots \text{or} \dots VI$$

$$= 162 * 2250 = \mathbf{364.5KW}$$
 for each electrode & they are four electrode

$$P_A = 4 * 364.5 = \mathbf{1458KW}$$

Calculate similarly the other side

$$P_B = \mathbf{1524.38KW} \ \& \ P_C = \mathbf{1476.66}$$

$$P_{Total} = P_A + P_B + P_C = \mathbf{4459.04}$$

5.4.3 Analysis of the Output Energy in the Melting Furnace

The total heat input is provided in the form of fuel or power. The desired output is the heat supplied for melting the material or process. Other heat outputs in the furnaces are undesirable heat losses. As reference [8] the energy output (losses) associated with the burning of furnace oil in the combustion chamber and the furnace as is indicated in Figure 6.1 the various losses that occur in the fuel fired furnace are listed below.

1. Dry flue gas loss
2. Heat loss due to evaporation of water formed due to H₂ in fuel
3. Heat loss due to moisture present in fuel
4. Heat loss due to radiation and convection from the melting furnace surface
5. Heat loss due to cooling of electrode
6. Heat carried away by molten glass
7. Unaccounted loss

1) Dry Flue Gas Loss Analysis

The energy loss due to dry flue gas leaving the melting 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 calculated using equation (6.17).

$$Q_{flue} = m_{flue} C_p (T_{flue} - T_a) \quad (6.17)$$

Where: T_{flue} - Flue temperature = 726 °C

T_a - Ambient temperature = 31 °C

$$\text{GCV of the fuel} = 10000 \text{ kCal/kg} = 41,870 \frac{\text{kJ}}{\text{kg}}$$

$$C_p - \text{Specific heat capacity of flue gas} = 0.573 \frac{\text{kCal}}{\text{kg}^\circ\text{C}}$$

$$\dot{m}_{flue} - \text{Mass flow rate of flue gas} = 4.2 \frac{\text{kg}_{flue}}{\text{sec}}$$

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

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

$$Q_{flue} = 4.2 \frac{\text{kg}_{flue}}{\text{sec}} \times 2.4 \frac{\text{kJ}}{\text{kg}^\circ\text{K}} (726^\circ\text{C} - 31^\circ\text{C})$$

$$Q_{flue} = 7005.6 \text{ kW}$$

2) Heat Loss Due to Evaporation of Water Formed due to Hydrogen in Fuel

During combustion process of the melting furnace oil the hydrogen in it react with oxygen and water will be formed. The water formed takes away some of the energy librated during the combustion process [8]. This energy loss due to hydrogen in the furnace oil is:

$$\% \text{ Loss} = \frac{9xH_2 \{584 + 0.45(T_{fg} - T_{amb})\}}{GCVofFuel} \times 100 \quad (6.18)$$

Where: H_2 – kg of H_2 in 1 kg of fuel oil (0.12 kg/kg of fuel oil)

$$T_{flue} - \text{Flue gas temperature} = 726^\circ\text{C}$$

$$T_a - \text{Ambient temperature} = 31^\circ\text{C}$$

$$Q_w = \frac{9 \times 0.12 \{584 + 0.45 \times 4.187(726 - 31)\}}{41870}$$

$$Q_w = 0.488 \text{ kW}$$

3) Heat Loss due to Evaporation of Moisture Present in Fuel

The furnace oil used for combustion contains moisture. The energy loss due to moisture present in the fuel is given by:

$$\% \text{ Loss} = \frac{Mx\{584 + 0.45(T_{fg} - T_{amb})\}}{GCVofFuel} \times 100 \quad (6.19)$$

Where: M - Kg of Moisture in 1 kg of fuel oil (0.5 kg/kg of fuel oil)

T_{fg} - Flue gas temperature

T_{amb} - Ambient temperature

HHV - Higher heating value of fuel oil

$$Q_m = \frac{0.5x\{584 + 0.45x4.187(726 - 31)\}}{41870}$$

$$Q_m = 0.226 \text{ kW}$$

4) Heat Loss due to Cooling of Electrode

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

$$[\text{feed ... water}]_{22^\circ c} \rightarrow [\text{feed ... water}]_{48^\circ c} \quad (6.20)$$

The energy due to pre-heating temperature can be obtained using the following equation (6.20)

$$Q_w = \dot{m}_w \times C_w \times (T_w - T_a) \quad (6.21)$$

Where

Q_w - Energy of feed water

\dot{m}_w - Mass flow rate of feed water (volume flow rate* density of water)

$$\dot{m}_w = 0.0021 \text{ Kg/s}$$

$$C_w \text{ - Specific heat of water} = 4.18 \frac{\text{kJ}}{\text{kg}^\circ\text{C}} [4]$$

$$T_w \text{ - Temperature of feed water} = 48^\circ\text{C}$$

$$T_a \text{ - Ambient temperature} = 22^\circ\text{C}$$

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

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

$$Q_w = 0.0021 \frac{kg}{s} * 4.18 \frac{kJ}{kg \cdot ^\circ C} * (48^\circ C - 22^\circ C)$$

$$Q_w = \mathbf{0.228 kW}$$

Number of electrodes is 12.

$$Q_{w..total} = \mathbf{2.74 kW}$$

5) Heat Loss due to Radiation and Convection from the Melting Furnace Skin

The quantity of heat loss from surface of furnace body is the sum of natural convection and thermal radiation. This quantity can be calculated from surface temperatures of furnace. The temperatures on furnace surface should be measured and their average should be used[8].

The quantity (Q) of heat release from a melting furnace is calculated with the following formula:

$$Q = \left\{ ax(T_1 - T_2)^{\frac{5}{4}} \right\} + \left\{ 4.88xE_x \left[\left(\frac{T_1 + 273}{100} \right)^4 - \left(\frac{T_2 + 273}{100} \right)^4 \right] \right\} \quad (6.22)$$

where: Q- Quantity of heat release in kCal / W / m²

a- heat transfer factor = 2.5

T₁ - Temperature of external wall surface of the furnace = 220.88°C

T₂ - Temperature of air around the furnace = 34°C

E- Emissivity of external wall surface of the furnace = 0.8

The first term of the formula above represents the quantity of heat release by natural convection, and the second term represents the quantity of heat release by radiation.

i) Heat loss through **roof and sidewalls** of melting zones:

$$Q = \left\{ \left\{ 2.5 * (220.88 - 34)^{\frac{5}{4}} \right\} + \left\{ 4.88 * 0.8 \left[\left(\frac{220.88 + 273}{100} \right)^4 - \left(\frac{34 + 273}{100} \right)^4 \right] \right\} \right\}$$

$$Q = 3703.33 \text{ kCal} / m^2 / \text{hr} = 15554 \text{ kJ} / m^2 / \text{hr}$$

$$\text{Heat loss at } 220.88^\circ C = 15554 \text{ kJ} / m^2 / \text{hr}$$

$$\text{Total area of melting} = 16 \text{ m}^2$$

$$\text{Heat loss} = 15554 \text{ kJ} / m^2 / \text{hr} \times 16 \text{ m}^2 = 248864 \text{ kJ/hr}$$

$$\text{Heat loss} = 69.13 \text{ kW}$$

6) The Heat Carried away by the Molten Glass

One of the major energy output is the heat carried away by the molten glass. The amount of heat energy carried away by the molten glass is obtained by using the following equation.

The useful energy can be obtained using equation (6.20).

$$Q_g = \dot{m}_g \times C_g \times (T_g - T_a) \quad (6.23)$$

Where: Q_g = Energy content due to the molten glass

$$C_g \text{ -Specific heat of glass} = 0.84 \frac{\text{kJ}}{\text{kg}^\circ\text{K}}$$

$$\dot{m}_g \text{ - Mass flow rate of the glass} = 3.2 \frac{\text{kg}}{\text{s}}$$

$$T_g \text{ -Glass outlet temp.} = 1345^\circ\text{C}$$

$$T_a \text{ - Glass feeding temp.} = 32^\circ\text{C}$$

Substitute the above data in (6.20) the useful energy content of the glass becomes:

$$Q_g = 3.2 \times 0.84 \times (1345 - 32)$$

$$Q_g = 3,529.34 \text{ kW}$$

7) Unaccounted Loss

These losses comprise of heat storage loss, heat loss by incomplete combustion, loss of heat by conduction through hearth and loss due to formation of scales.

5.5 Analysis of Mass and Energy Balance of the Melting Furnace

The balance equations are used in an analysis of a process, which determines input to output to a system. There are several types of balance equations, which may prove useful in the analysis of a melting furnace. These include a mass balance and energy balance.

5.5.1 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 melting

furnace. These are mass balance for the combustion process and mass balance for the working media.

1) Mass Balance for the Combustion Process

The mass balance for the combustion process is consisting of actual air supplied and furnace oil are input mass and excess oxygen, nitrogen, carbon dioxide and sulphur dioxide are output mass.

Table 5.7 Summary of Melting Furnace Input-Output Mass for Combustion Process

No	Source	Mass in kg
Input mass		
1	Fuel	1
2	Actual air supplied	32.85
	Total	33.85
Output mass		
1	Excess O ₂	4.35
2	N ₂	25.29
3	CO ₂	3.083
4	H ₂ O	1.08
5	SO ₂	0.03
	Total	33.83

5.5.2 Analysis of Energy Balance

The heat from fuel appears as useful heat to the product plus heat losses to the environment. A heat balance is used to determine where all the heat energy enters and leaves. Assuming that energy can neither be created nor destroyed, all energy can be accounted for in a system analysis.

Table 5.8 Summary of Melting Furnace Input-Output Energy

No	Source	Energy in kW
Input energy		
1	Fuel due to its heat content	7774.8
2	Fuel sensible heat	9

3	Combustion air	0
4	Feed batch	0
5	Electrical energy	4459.04
	$\sum_{i=1}^4 \text{Energy Inputs}$	12242.84
	Output energy	
1	Heat loss due to dry flue gas	7005.6
2	Heat loss due to hydrogen in furnace oil	0.488
3	Heat loss due to moisture in air	0.226
4	Surface losses	69.13
5	Heat loss due to cooling of electrode	2.74
6	Heat is carried away by the molten glass	3529.34
	$\sum_1^5 \text{Energy} \dots \text{losses}$	7078.18
	$\sum_1^6 \text{Energy} \dots \text{losses}$	10607.52

5.5.3 Concluding Remark on the Mass and Energy Balance Result of the Melting Furnace

The above mass balance analysis of the combustion process of the melting furnace 100% input mass to the melting furnace should be 96.74% of output mass. This indicates that the summation of input mass and output mass for combustion process are not matching for the melting furnace. These differences may be due to personal error when measurement is taken in the company. Even though there is numerical difference, but the result obtain from mass balance of combustion process is at an acceptable percent. In the mass balance of the working media of the melting furnace 100% input mass to the melting furnace should be 100% output mass. This implies that there is no loss observed in the melting furnace. For the heat balance of the melting furnace for 100% input energy to the melting furnace 47.85% is lost. This indicates that the summation of input energy and output energy are not matching for the melting furnace. These

difference may be due to flue gas loss and wall energy loss of the melting furnace, which can be considered as energy conservation opportunities.

5.6 Efficiency of the Melting Furnace

Efficiency, which does account for radiation and convection loss, is a true indication of melting furnace efficiency [19]. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses.

Then the efficiency of the melting furnace is given by 6.24

Substitute the values of the summations of energy losses and energy inputs from Table 6.7 the thermal efficiency is given by:

$$\eta = \left[1 - \frac{\sum_{i=1}^5 \text{Energy Losses}}{\sum_{i=1}^4 \text{Energy Inputs}} \right] \times 100\% \quad (6.24)$$

$$\eta = \left[1 - \frac{7078.12}{12242.84} \right] 100\%$$

$$\eta = 42\%$$

5.7 Energy Sankey Diagram of the Melting Furnace

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 various output and losses so that the energy managers can focus on finding improvements in a prioritised manner [39]. The energy Sankey diagram of the melting furnace is drawn using the heat balance described above and is revealed in Figure 6.2.

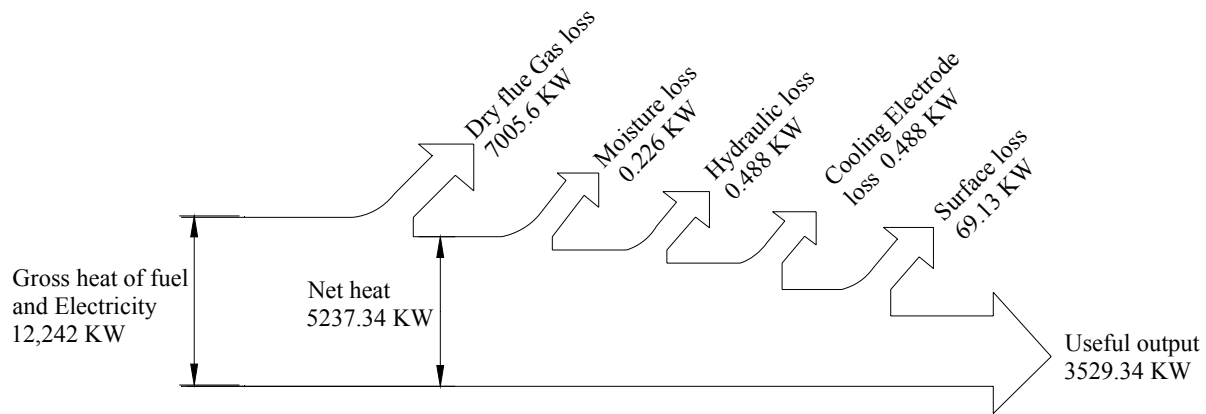


Figure 5.2 Energy Sankey Diagram of the Melting Furnace

5.8 General Comment of the Energy Performance of the Melting Furnace

The energy efficiency of the melting furnace of the company is found 42%. This efficiency is less than the expected performance of the melting furnace, which is equal to 65% [4]. The main causes that contribute to the significant drop in efficiency of the melting furnace are the energy loss due to: dry flue gas loss, hydrogen in furnace oil, moisture in fuel oil, and melting furnace surface loss and unaccounted loss. The energy loss due to furnace oil hydrogen content and moisture content in the fuel are unavoidable losses. But energy loss due to dry flue gases & melting furnace surface energy loss can be reduced. Therefore minimizing these energy losses are considered as energy conservation opportunities that could significantly improve the energy efficiency of the melting furnace.

5.9 List of ECOs Identified from the Audit Analysis

Implemented energy conservation opportunities are energy management actions which are done once and for which the cost is significant.

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

1. Use the recuperator in the flue gas outlet.
2. Reinsulated the furnace enclosure.
3. Minimize furnace excess air.

5.10 Economical and Technical Evaluation of the ECO_s Proposed for the Melting Furnace System

According to detail energy audit of the melting furnace, saving energy in the company melting furnace is a question of improving efficiency. In accordance with this fact the result of energy audit conducted in this chapter revealed that there is a considerable energy savings potential in the melting furnace of the company through improving the melting furnace efficiency, which reduces the energy losses, listed above is described below.

5.10.1 Economical Evaluation of Installing the Recuperator in the Flue Gas Outlet

The economic and technical analysis that follows is based on an actual installation of new high-alloy recuperators applied to continuously operating furnace [15]. Total cost of the new recuperator is 1,500,000 Birr. Fuel consumption before conversion was 213.87 kW. The annual fuel cost was 2,028,547.2 Birr.

To estimate the savings, it is necessary to determine the recuperator performance. The flue gas living the chimney has a temperature of 726^oC. and the combustion air is heated from ambient to 500^oC. The excess air before conversion is 36 percent. The intersection of 36 percent excess air and 726^oC on figure 6.3 indicates that 42 percent of the heat supplied in the fuel is lost in the flue gas.

$$\text{Flue gas heat loss} = \frac{42}{100} \times 213.87 \text{ kW} = 89.83 \text{ kW}$$

The remaining 124.04 kW pass through the chimney of the furnace. Using figure 6.3 with 36 percent excess air and 726^oC flue gas temperature shows that 42 percent of the heat supplied is lost, and 58 percent enters the furnace.

$$\text{Burner energy} = \frac{124.04}{0.80} = 155.05 \text{ kW}$$

$$\text{Heat loss} = 155.05 \text{ kW} - 124.04 \text{ kW} = 31.01 \text{ kW}$$

$$\text{Energy savings} = 89.83 \text{ kW} - 31.01 \text{ kW} = 58.82 \text{ kW}$$

$$\text{Savings} = \frac{58.82}{213.87} = 28\%$$

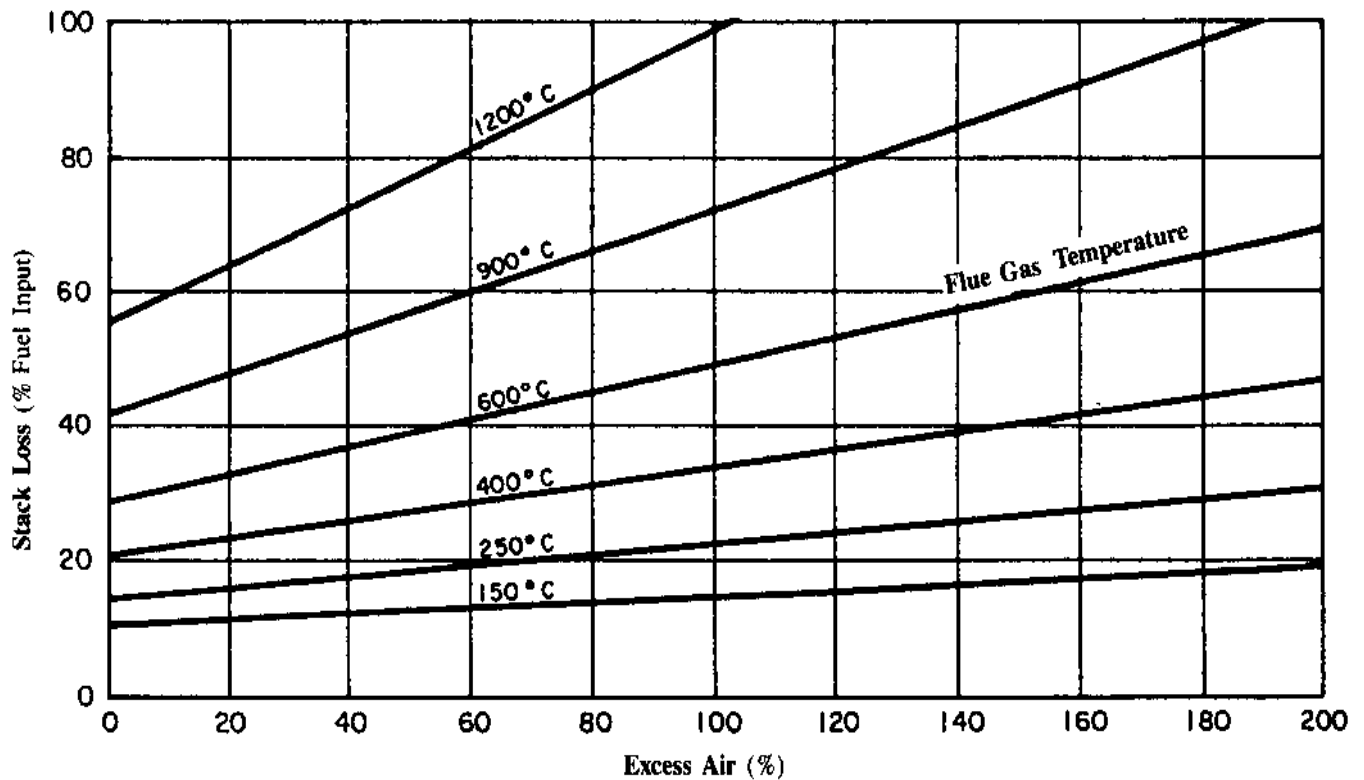


Figure 5.3 Flue Gas Loss of Fuel Oil

The annual fuel savings were 28 percent of 2,028,547.2 Birr or about 567993.22 Birr.

Therefore the simple payback period = Implementation Cost / Annual Cost savings.

$$\text{Payback period} = \frac{1,500,000}{567993.22} = 2.6 \text{ years.}$$

5.10.2 Economical Evaluation of Reinsulated the Furnace Enclosure

Addis Ababa Bottle & Glass Share Company uses refractory brick for the furnace lining. But it is frequently economical to use ceramic fibre blanket insulation. If refractory brick is required to withstand rough handling, an outer layer of ceramic fibre can be used. Since ceramic fibre is a much better insulator than refractory brick, care should be taken to ensure that the inner layer of refractory is not overheated & its average temperature will be higher. The temperature measurement of the surface average is 221^oc. The dimensions and areas from table6.2.

The glass melting furnace is hexagonal in shape. The six sides of the wall area are equal and also the top and bottom are equal.

$$\text{Total area} = A_{(\text{sides} \dots \text{wall})} + A_{(\text{top} \dots \text{bottom})}$$

$$A_{\text{sides}\dots\text{wall}} = L * H = 2 * 1.375 = 2.75 \text{m}^2$$

$$A_{(S\dots W)\text{Total}} = 6 * 2.75 = \underline{16.5 \text{m}^2}$$

$$A_{\text{top}\dots\text{bottom}} = A_{(\text{Triangle})} + A_{\text{Rectangle}} = 2 * \frac{1}{2} a * b \sin \theta + L^2$$

$$A_{(\text{top}\dots\text{bottom})} = 2 * \frac{1}{2} * 2 * 2 * \sin 120^\circ + (2 * 2) = 7.5 \text{m}^2$$

$$A_{(T\dots B)\text{Total}} = 2 * 7.5 = \underline{15 \text{m}^2}$$

Total area = **31.5m²**

According to [6] to give a maximum surface temperature of 50 °c and to provide operator safety and heat savings we have to reinsulate the furnace using ceramic fibre. The cost of the new ceramic fibre per m² is 12,184 Birr. Therefore the total cost of the insulation is 12,184 Birr * 31.5m² = 383,796 Birr. From the figure 5.6, heat losses are

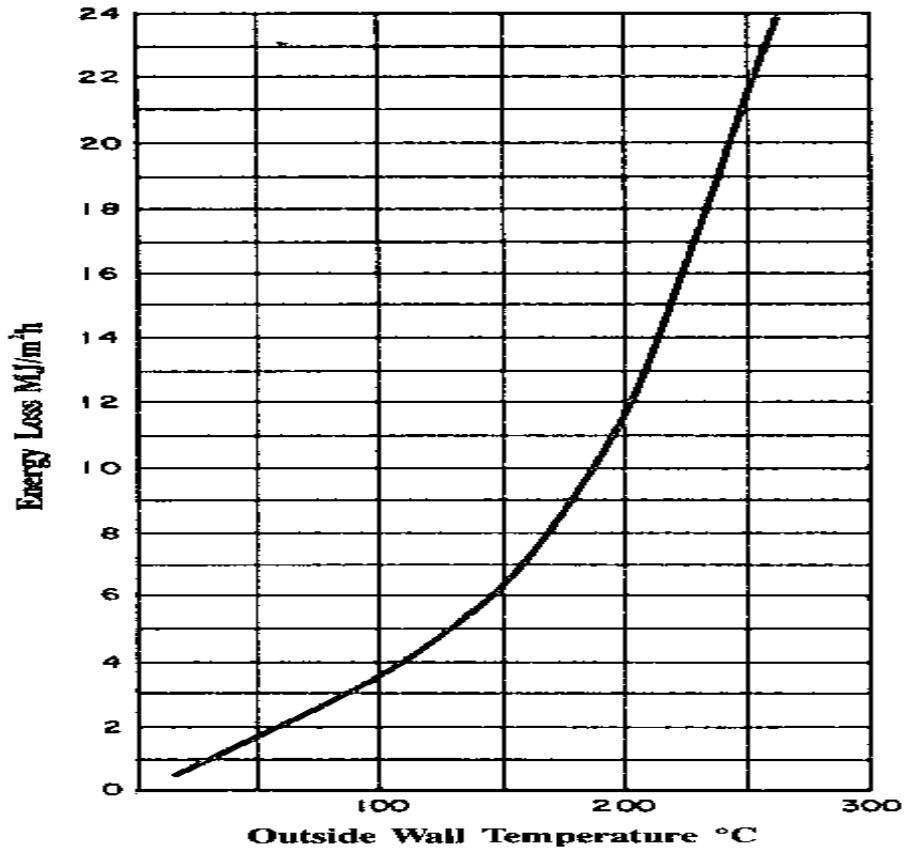


Figure 5.4 Energy Losses from Furnace Walls Versus Outside Wall Temperature

$12,000 \frac{kJ}{m^2h}$ at $221^\circ C$ but $1,700 \frac{kJ}{m^2h}$ at $50^\circ C$.

Heat loss before reinsulated = $[12,000 \frac{kJ}{m^2h} \times 31.5m^2] = 378,000 \frac{kJ}{h} = 105 \text{ kW}$

Heat loss after reinsulated = $1,700 \frac{kJ}{m^2h} \times 31.5m^2 = 53550 \frac{kJ}{h} = 14.88 \text{ kW}$

Energy savings = $105 \text{ kW} - 14.88 \text{ kW} = 90.12 \text{ kW}$

The furnace operates 4,300 hours per year and fuel costs 9.49 Birr per litre

$$\text{Annual savings} = \frac{324432kJ / hx4300h / year \times 9.49 \text{ Birr}}{41870kJ}$$

Annual savings = 984,175 Birr/year

Therefore the simple payback period = Implementation Cost / Annual Cost savings.

$$\text{Payback period} = \frac{383796}{984175} = 0.4 \text{ years.}$$

5.10.3 Summary of Technically and Economically Feasible ECOs

The following are technically as well as economically feasible ECOs that play crucial role in improving the melting furnace efficiency:

- 1) Install recuperator
- 2) Reinsulating the melting furnace with ceramic fibre
- 3) Keeping the percentage of the excess air within the recommended range

The summary of the energy saving recommendations and the priority for post audit analysis are summarized in Table 6.9.

Table 5.9 Summary of the Energy Saving Recommendation & Priority

No.	Types of Energy Saving Recommendation	Yearly Saving (Birr)	Capital investment (Birr)	Simple Payback (year)	Priority
1	Replacing the recuperator with new one	764,182.5	1,200,000	2.6	1 st
2	Reinsulated the furnace with ceramic fibre	984,175	1,513,496.5	0.4	2 nd
3	Controlling excess air	-	-	-	3 th

CHAPTER 6

6 DETAILED ENERGY AUDIT OF MOTOR AND ITS PRIME MOVERS

6.1 Introduction

An initial company energy survey shows where and how energy is being used and/or wasted. An inventory of energy-using equipment should be prepared, showing basic energy use data (usually obtained from equipment nameplates) and indicating typical running time and operating profiles. Without basic audit information, it is impossible to tell whether equipment is operating unnecessarily or wastefully. The basic survey information is also needed to set standards, and to measure the performance of an individual piece of equipment, a processing line. Survey information also assists the energy coordinator to “target” and focus efforts on the most energy-intensive equipment in a company.

Using a “systems approach” to optimize supply and demand of energy services can often yield increased savings. For example, in pumping, a systems approach analyzes both the supply and demand sides and how they interact, shifting the focus of the analysis from individual components to total system performance. The measures we identify below reflect aspects of this system approach including matching speed and load (variable speed drives), sizing the system correctly, as well as upgrading system components.

Motors represent the largest user of electricity in the company. 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 company motor system is composed of fourteen motors in number excluding the fourteen stand by motors. From this five motors are used to drive pumps, six motors are used to drive cooling tower fans and melting furnace combustion fan and three motors used to drive air compressor. In order to evaluate the performance of motors with its driven machines; data gathered at motors and the driven machines by measuring using

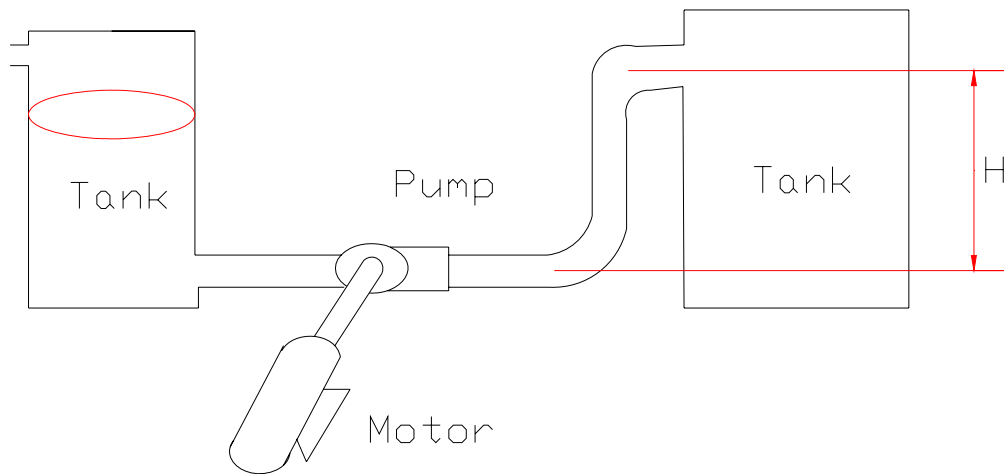


Figure 6.1 Schematic Diagram of the Company Pump System

portable measuring instruments, from nameplate of the machines and annual operating hours of the machine. Therefore the detail energy audit of these major prime movers with their motors can be performed through assessment of their energy performance according to the following categories in the sub sections of this chapter.

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

6.2 Performance Evaluation of Pumps with their Motors

Pumps come in a variety of sizes for a wide range of applications. They can be classified according to their basic operating principle as dynamic or displacement pumps. Dynamic pumps can be sub-classified as centrifugal and special effect pumps. Displacement pumps can be sub-classified as rotary or reciprocating pumps. In principle, any liquid can be handled by any of the pump designs. Where different pump designs could be used, the centrifugal pump is generally the most economical followed by rotary and reciprocating pumps. Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs[21].

6.2.1 Centrifugal Pumps

A centrifugal pump is of a very simple design. The two main parts of the pump are the impeller and the diffuser. Impeller, which is the only moving part, is attached to a shaft and driven by a motor. Impellers are generally made of bronze, polycarbonate, cast iron, stainless steel as well as other materials. The diffuser (also called as volute) houses the impeller and captures and directs the water off the impeller. Water enters the center (eye) of the impeller and exits the impeller with the help of centrifugal force. As water leaves the eye of the impeller a low-pressure area is created, causing more water to flow into the eye. Atmospheric pressure and centrifugal force cause this to happen. High velocity is developed as the water flows through the impeller spinning at high speed. This velocity is converted to pressure by the diffuser through specially designed passageways that direct the flow to the discharge of the pump, or to the next impeller should the pump have a multi-stage configuration. The pressure (head) that a pump will develop is in direct relationship to the impeller diameter, the number of impellers, the size of impeller eye, and shaft speed. Capacity is determined by the exit width of the impeller. The head and capacity are the main factors, which affect the horsepower of the motor to be used. The more the quantity of water to be pumped, the more energy is required.

A centrifugal pump is not positive acting; it will not pump the same volume always. The greater the depth of the water, the lesser is the flow from the pump. Also, when it pumps against increasing pressure, the less it will pump. For these reasons it is important to select a centrifugal pump that is designed to do a particular job. Since the pump is a dynamic device, it is convenient to consider the pressure in terms of head i.e. meters of liquid column. The actual contours of the hydraulic passages of the impeller and the casing are extremely important, in order to attain the highest efficiency possible. The standard convention for centrifugal pump is to draw the pump performance curves showing flow on the horizontal axis and head generated on the vertical axis. Efficiency, Power & NPSH are conventionally shown on the vertical axis, plotted against Flow, as illustrated in Figure 6.2.

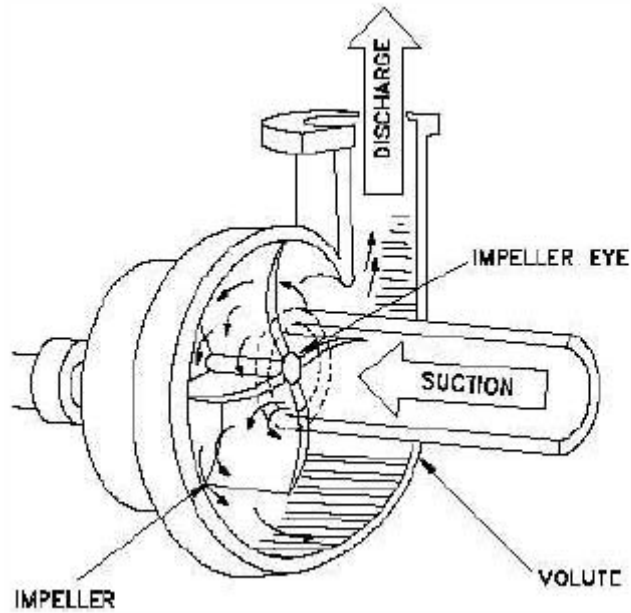


Figure 6.2 Centrifugal Pump

The pump is among the most inefficient of the components that comprise a pumping system, including the motor, transmission drive, piping and valves.

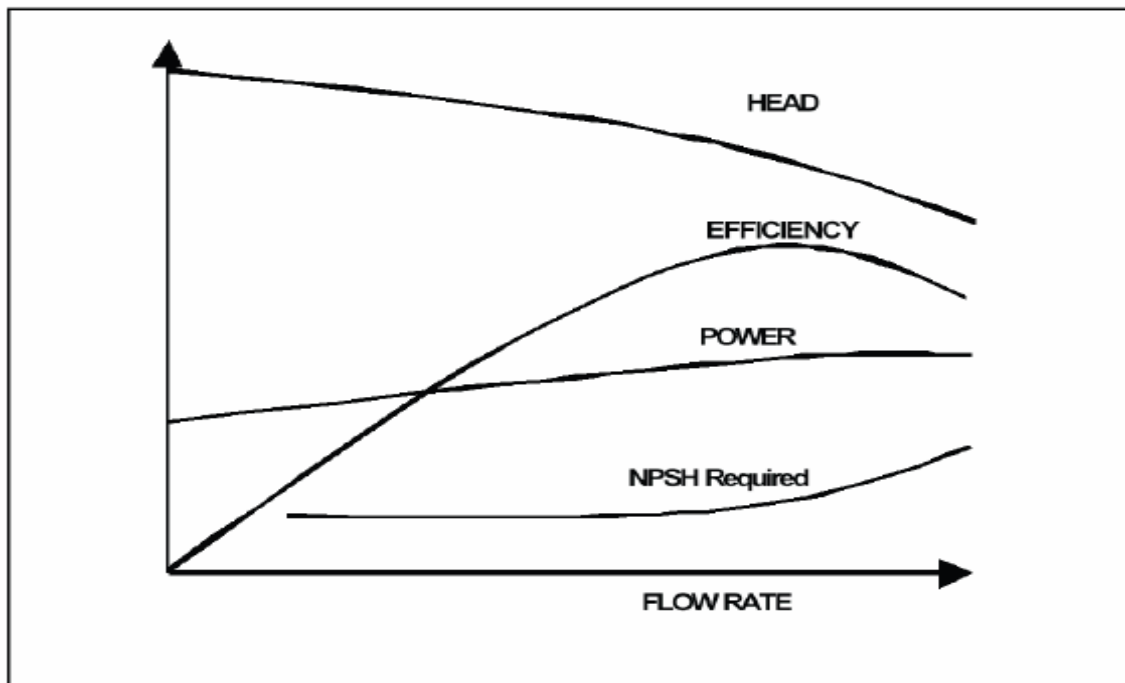


Figure 6.3 Pump Performance Curve

The main functions of company pumps are to transfer liquid like cooling water and furnace fuel oil. All pumps are centrifugal in types and its motors are three-phase AC induction motors. In order to analysis energy performance of the pumps with a motor, data must be collected from nameplate and measurements.

6.2.2 Collected Data

To compare operating costs of an existing motor and a more efficient replacement unit, you need to determine operating hours, efficiency improvement values, and load. Part-load is a term used to describe the actual load served by the motor as compared to the rated full-load capability of the motor. Motor part-loads may be estimated through using input power, amperage, or speed measurements. Several load estimation techniques are briefly discussed.

When “direct-read” power measurements are available, we recommend using them to estimate motor part-load. With measured parameters taken from hand-held instruments. You can then quantify the motor’s part-load by comparing the measured input power under load to the power required when the motor operates at rated capacity.

The current load estimation method is recommended when only amperage measurements are available. The amperage draw of a motor varies approximately linearly with respect to load, down to about 50 percent of full load. (See Figure 5-1) Below the 50 percent load point, due to reactive magnetizing current requirements, power factor degrades and the amperage curve becomes increasingly nonlinear. In the low load region, current measurements are no longer a useful indicator of load. Both nameplate full-load and no load current values apply only at the rated motor voltage. Thus, root mean square current measurements should always be corrected for voltage. If the supply voltage is below that indicated on the motor nameplate, the measured amperage value is correspondingly higher than expected under rated conditions and must be adjusted downwards. The converse holds true if the supply voltage at the motor terminals is above the motor rating.

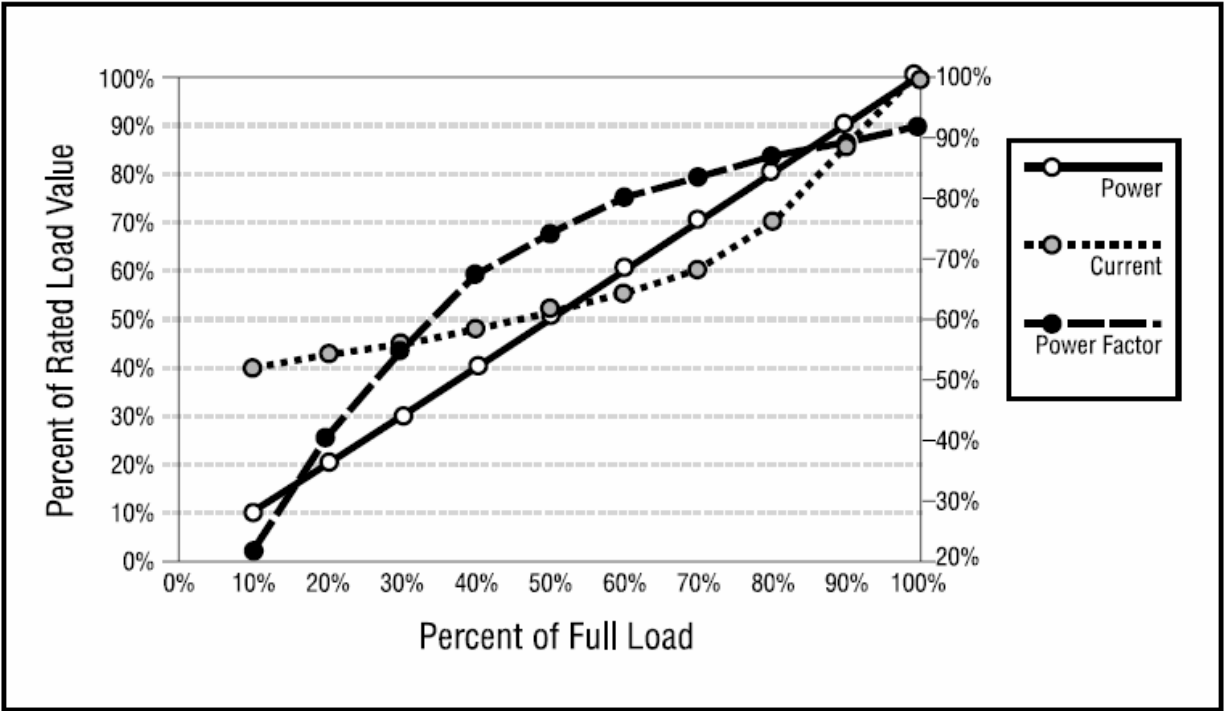


Figure 6.4 Relationships between Power, Current, Power Factor & Motor Load

Data collected at company pumping system on its motors and pumps.

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

Data on pumps: it includes measured fluid flow velocity, pump head and pipe diameter using portable measuring instruments and annual operating hours and fluid density. The collected data are recorded in table 6.1 and 6.2.

Table 6.1 Company Motor Data

Motors	Name plate			Measured		
	I(A)	V(v)	P(kW)	I(A)	V(v)	P (kW)
1. Water pump motor No. 1	11.8	380	5.5	11.2	379.3	4.87
2. Water pump motor No. 2	11.8	380	5.5	11.2	379.1	4.87
3. Circulation water pump motor No. 1	323	380	15	320	378.75	14.78
4. Circulation water pump motor No. 2	323	380	15	320	378.34	14.72
5. Heavy oil pump motor 1	1.5	380	0.559	2.01	379.55	0.499

6.Heavy oil pump motor 1	1.5	380	0.559	2.01	379.43	0.501
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Table 6.2 Company Pump Data

Pumps	Measured Data				
	ρ (kg/m ³)	ΔH (m)	V(m/s)	D (m)	Operating Hours
1. Water pump motor No. 1	1000	5.45	2.16	0.08	4021
2. Water pump motor No. 2	1000	5.45	2.16	0.08	4021
3. Circulation water pump motor No. 1	1000	11.23	5.05	0.071	4021
4. Circulation water pump motor No. 2	1000	11.23	5.05	0.071	4021
5. Heavy oil pump motor 1	991	3.95	0.62	0.061	2800
6. Heavy oil pump motor 1	991	0.75	3.01	0.060	2800

6.2.3 Data Analysis

To conduct the energy analysis and to find the overall efficiency of pumps with its motors the following parameters must be determine.

1. Nameplate input power of the motors
2. Load factor of the motors
3. Actual power factors of the motors
4. Volume flow rate of the fluid
5. Power gained by the fluid
6. Overall efficiency

1 Nameplate Input Power of the Motors

The nameplate power factor of the motors can be calculated[19] using equation (7.1)

$$PF = \frac{1000P_m}{V * I * \sqrt{3}} \quad (6.1)$$

Where: P_{int} - Nameplate input power

V - Rated (nameplate)

I -Rated (nameplate)

PF-power factor

Using data from table 6.1 and substitute in equation (6.1) the name plate power factor of the motors is tabulated in Table 6.3

2 Load Factor of the Motors

The electric motors are designed to run at 50 to 100 percent of rated load. Under loaded motors, those loaded below 50 percent of rated load, are inefficient and exhibit low power factor.

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 (6.2).

$$L.F = \frac{P_{in(actual)}}{P_{in(nameplate)}} \quad (6.2)$$

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

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

Using data from table 6.3 and substitute in (6.2) the load factor of the motors of the pumps are tabulated in Table 6.3

3 Actual power factors of the motors

Power factor is a measurement of the phase angle lag between electrical voltage and current.

Low power factor results in increased electrical distribution system losses.

The actual power factor of the motors is given by equation (6.3).

$$\cos \phi = \frac{P_{in(actual)}}{I_m * V_m * \sqrt{3}} \quad (6.3)$$

Where: $\cos \phi$ – Power factor

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

I_m – Measured current

V_m – Measured voltage

Using data from table 6.1 and substitute in equation (6.3) the actual power factor of the motor of the pumps tabulated in Table 6.3

4 Volume flow rate of the fluid

The volumetric flow rate in fluid dynamic and hydrometric, (also known as volume flow rate or rate of fluid flow) is the volume of fluid which passes through a given surface per unit time.

The volume flow rate of the fluid is given by equation (6.4).

$$\dot{Q} = V_{fluid} * A_{pipe} \quad (6.4)$$

Where: V_{fluid} – Fluid flow velocity

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

Using data from table 6.2 and substitute in (6.4) the volume flow rate of the pump is tabulated in Table 6.3

5 Power gained by the fluid

The power gained by the fluid is given by equation (6.5).

$$P_{out} = \frac{\rho \times g \times \Delta H \times \dot{Q}}{1000} \quad (6.5)$$

Where: P_{out} – Power gained by the fluid

ρ -Density of fluid

g -Acceleration due to gravity

ΔH -Pump head

\dot{Q} -Volume flow rate of fluid

6 Overall efficiency

The definition of energy efficiency is the ratio of its useful power output to its total power input and is usually expressed in percentage. By definition, a motor of a given rated horsepower is expected to deliver that quantity of power in a mechanical form at the motor shaft. Figure 6-5 is a graphical depiction of the process of converting electrical

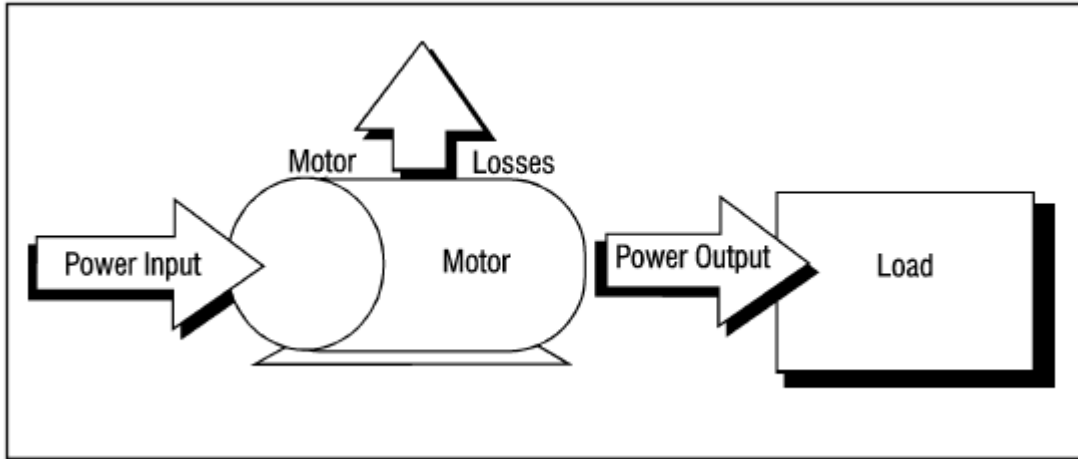


Figure 6.5 Depiction of Motor Losses

energy to mechanical energy. Motor losses are the difference between the input and output power. Once the motor efficiency has been determined and the input power is known, you can calculate output power.

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

$$\eta_{overall} = \frac{P_{out (Pump)}}{P_{in(actual)}} \quad (6.6)$$

Where: P_{out} – Power gained by the fluid

$P_{in(actual)}$ – Electric energy

Using data from table 6.1 and 6.2 and substitute in (6.6) the overall efficiency of pump with its motor is tabulated in Table 6.3.

Table 6.3 Summary of Data Analysis Company Pump with its Motor

Motor or Pump	PF	$P_{in(actual)}$ (kW)	LF	$Cos \phi$	\dot{Q} (m^3 / s)	P_{out} (kW)	$\eta_{Overall}$
1	0.708	4.87	0.885	0.662	0.0108	0.5886	0.121
2	0.708	4.87	0.885	0.662	0.0108	0.5886	0.121
3	0.071	14.78	0.985	0.07	0.02	2.246	0.152
4	0.071	14.72	0.981	0.07	0.02	2.246	0.153

5	0.566	0.499	0.896	0.746	0.0018	0.0705	0.141
6	0.566	0.501	0.893	0.75	0.0084	0.062	0.124

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

The overall efficiency of the six pumping system are 12%, 12%, 15%, 15%, 14% and 12%. According to [14] an average motor efficiency is 85% and average pump efficiency is 60%. The recommended overall efficiency of pumping systems will be $85\% * 60\% = 51\%$. Therefore the overall efficiency of the six pumping system are well below the recommended value and this drop in efficiency of the pumping systems can be considered as an energy conservation opportunity.

6.2.5 List of ECOs Identified

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

1. Ensure availability of basic instruments at pumps like pressure gauges, flow meters.
2. Operate pumps near best efficiency point.
3. Modify pumping system and pumps losses to minimize throttling.
4. Repair seals and packing to minimize water loss by dripping.
5. Balance the system to minimize flows and reduce pump power requirements.
6. Conduct water balance to minimize water consumption
7. In multiple pump operations, carefully combine the operation of pumps to avoid throttling
8. Reduce system resistance by pressure drop assessment and pipe size optimization
9. Most of the pumps are exposed to dirt.
10. Leakage is observed in most of the pumps.
11. The power factor of the motors of the pumps is low.
12. The overall efficiency of the pumping systems are low due to most of the motors being oversized and under loaded.
13. Replace old pumps by energy efficient pumps
14. Modify pumping system and pumps losses to minimize throttling.
15. Adapt to wide load variation with variable speed drives or sequenced control of multiple units.

6.2.6 Technical Evaluation of the ECOs

The detail energy audit of the pumping system, saving energy in the company pumping system is an improving of overall pumping efficiency. In 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 company through improving the overall pumping efficiency, which reduces the energy losses, listed above. Therefore the technical feasibility analysis of ECOs number 1 up to 10 are no cost or low cost and can be handled by routine maintenance program. For ECOs number 11 up to 15 the company must be consider the motor power factor when the existing motors have failed or need replacement. Therefore the technical analysis of improving overall efficiency of pumping system by replacing the oversized and under loaded motors with appropriate sized motors is discussed below.

6.2.7 Technical Evaluation of Improving Overall Efficiency of Pumping System

An average overall efficiency of pumping system is 51% [18]. From the energy analysis conducted above the efficiency of the six pumping systems are 12%, 12%, 15%, 15%, 14 and 12%. This indicates that the company pumping system waste an average of 86.67% of the energy input on electric power. This energy waste signifying that details of the energy wastages causes must be investigated and measures must be taken to improve the energy efficiency of the pumping systems. The main reason of energy losses in the company pumping system is energy loss due to oversized and under loaded motor. This energy loss can be minimized to an optimum level through replacing the existing oversized and under loaded motors by appropriate sized motors. To find appropriate motor power capacity of the pump for increasing the overall efficiency of pumping system and reduce energy losses the following calculation are essential: pump volume flow rate, pump head and motor load factor.

1) Estimation of Pump Volume Flow Rate

The volume flow rates of each pump are measured, calculated and tabulated in table 6.3. But in order to find the optimum level of flow rate it is better to take 20% margin on flow, therefore the optimum volumetric flow will be:

$$\dot{Q}_{i (Optimum)} = 1.2 \dot{Q}_{i (Measured)} \quad (6.7)$$

Where: $\dot{Q}_{i (Optimum)}$ – Optimum value of volume flow rate of each pump

$\dot{Q}_{i (Measured)}$ – Measured value of volume flow rate of each pump [Table 6.3]

Substitute the measured value of volume flow rate from (Table 6.3) in equation (6.7) the optimum value of volume flow rate of all pumps tabulated in Table 6.4.

2) Estimation of Pump Head

The pumps head are measured, calculated and tabulated in table 6.2. But in order to find the optimum level of pump head it is better to take 20% margin on head, therefore the optimum head will be:

$$\Delta H_{i(Optimum)} = 1.2\Delta H_{i(Measured)} \quad (6.8)$$

Where: $\Delta H_{i(Optimum)}$ – Optimum value of head of each pump

$\Delta H_{i(Measured)}$ – Measured value of head of each pump [Table 6.2]

Substitute the measured value of head from (Table 6.2) and substitute in equation (6.8) the optimum value of head of all pumps tabulated in Table 6.4.

3) Estimation of Load Factor of Motor

According to [24] the optimum value of motor load factor is ranging from 60% - 80%. Thus we will take 70% as an average value of load factor for determination of an appropriate motor power capacity of the pump.

4) Motor Power Capacity of the Pump

Assuming pump efficiency as 60% and motor efficiency as 90% the motor capacity for the pumps are given by the equation (7.9).

$$P_{Optimum} = \frac{\rho_{fluid} * g * \Delta H_{i(Optimum)} * \dot{Q}_{i(Optimum)}}{\eta_M * \eta_P} \quad (6.9)$$

Substitute the above data from (Table 6.2) and (Table 6.4) in equation (6.9) the optimum value of power capacity of the pumps are tabulated in Table 6.4. Hence the rated (nameplate) power of the motor is given by equation (6.10) and the result is tabulated in table 6.4.

$$P_{Nameplat} = \frac{P_{Optimum}}{L.F_{Optimum}} \quad (6.10)$$

Table 6.4 Summary Motor Power Capacity of the Pumps

Pump with its Motor	$\Delta H_{Opt} (m)$	$\dot{Q}_{Opt} (m^3 / s)$	$L.F_{Opt}$	$\eta_M * \eta_P$	$P_{Opt} (kW)$	$P_{New} (Nameplate)$
1	6.54	0.01296	0.7	0.54	1.57	2.243
2	6.54	0.01296	0.7	0.54	1.57	2.243
3	13.476	0.024	0.7	0.54	5.99	8.557
4	13.476	0.024	0.7	0.54	5.99	8.557
5	4.74	0.00216	0.7	0.54	0.188	0.268
6	0.9	0.01008	0.7	0.54	0.165	0.236

The above table indicates that for the same power gained by the fluid it is possible to reduce the rated or nameplate motor capacity; therefore it is recommended to replace the existing motor by new motor capacity listed in the table 6.4.

6.2.8 Lists of Technically Feasible ECOs

1. The pumps are not cleaning.
2. Not record operating conditions at regular intervals.
3. Leakage is observed in most of the pumps.
4. The power factor of the motors of the pumps are low
5. Replace the oversized and under loaded motors.

6.2.9 Economical Evaluation of the Technically Feasible ECOs

The economic analysis of the feasible energy conservation opportunities of ECOs 1 up to 4 are no cost and/or low cost energy conservation opportunities that can be handled in routine maintenance program. The economic analysis of replacing the oversized and under loaded motors is discussed below.

6.2.10 Economical Evaluation of the Replacing of Oversized and Under Loaded Motors

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.

1) Energy Saving Analysis

The results of the energy audit analysis performed so far it is known that the energy is saved by replacing the existing oversized and under loaded motors by appropriate sized and optimum loaded motors. The energy saving analysis is given by equation (6.11).

$$E.S = (P(i)_{Old (Nameplate)} - P(i)_{New (Nameplate)}) \quad (6.11)$$

Where: $P(i)_{Old (Nameplate)}$ - The existing motors nameplate power

$P(i)_{New (Nameplate)}$ - The new motors nameplate power

Saving in terms of money can be given by equation (6.12).

$$M.S = E.S * Cost (Birr) / kWh * (M(i)_{Operating hours}) \quad (6.12)$$

Where: $M.S$ - Money saved

$Cost / kWh$ - cost per kWh = 0.5778 Birr/kWh [EEPC]

$M(i)_{Operating hours}$ - Motors operating hours

Using data from table 6.2, 6.3 and 6.4 and substitute in equation (6.11) and (6.12) the value of saved energy and money is tabulated in table 6.5.

2) Cost Analysis

According to [14] the costs of typical motors are varying according to rated power of the motors this means the rated power of the motors and the costs of the motors have a direct relationship. Therefore according to market analysis the cost of the replaced motors are tabulated in table 6.5.

3) Payback Period

The payback period can be found by dividing the cost saved with the cost of motors. Adding 47% [15] additional cost on the direct average cost of purchasing the motors for transportation and other related costs. The cost of having the motors will be $1.47 * Cost of Motors$

$$Payback Period = \frac{1.47 * Cost of Motors}{Cost Saved} \quad (6.13)$$

Using data of motor cost and cost saving from replacement of motors from table 6.5 and substitute in the equation (6.13) the payback is given and tabulated in table 6.5.

Table 6.5 Economic Evaluation of Replacing Oversized Motors

<i>Motor</i>	<i>E.S(kW)</i>	<i>Annual Saving (Birr /Year)</i>	<i>Cost(birr)</i>	<i>Payback (Year)</i>	<i>LT(year)</i>	<i>Remark (Economically)</i>
1	3.257	7905.84	9,800.00	1.82	10	Feasible
2	3.257	7905.84	9,800.00	1.82	10	Feasible
3	6.443	15639.34	12,900.00	1.21	10	Feasible
4	6.443	15639.34	12,900.00	1.21	10	Feasible
5	0.291	470.79	3,200	9.99	10	Feasible
6	0.323	522.56	3,200	9	10	Feasible

6.2.11 Concluding Remark on Replacing the Oversized Motors

The audit result shown in the above table 6.5 replacing of the oversized and under loaded motors with appropriate sized and optimum loaded is technically as well as economically feasible energy conservation opportunities. Therefore the company replaces the six economically feasible motors; it can save 48083.71 birr per year.

6.3 Performance Evaluation of Fans with its Motors

The company has three fans, two of them are identical axial variable pitch-in motion type, which are used to perform the cooling process of cooling the melting furnace. The third one is a vacuum centrifugal backward curved type, which is used to supply combustion air to the melting furnace. All fans use three-phase AC induction motors to perform their activity.

Measurement data on cooling tower fans is impossible due to fans installed inside the melting furnace and for combustion air fan is impossible to conduct actual energy analysis.

6.4 Performance Evaluation of Air Compressor with its Motor

6.4.1 Introduction

Air compressors account for significant amounts of the electricity used in industries. Air compressors are used in a variety of industries to supply process requirements, to operate pneumatic tools and equipment, and to meet instrumentation needs. Only 10%–30% of energy reaches the point of end use; the remaining 70%–90% of energy of the power of the prime mover

is converted to unusable heat energy and to a lesser extent is lost in the form of friction, misuse, and noise. Compressors are broadly classified as positive displacement compressors and dynamic compressors.

6.4.2 Compressor Types

Positive displacement compressors increase the pressure of the gas by reducing the volume. Positive displacement compressors are further sub classified as reciprocating or rotary compressors.

Dynamic compressors increase the air velocity, which is then converted to increased pressure at the outlet. Dynamic compressors are basically centrifugal compressors and are further classified as radial and axial flow types[21].

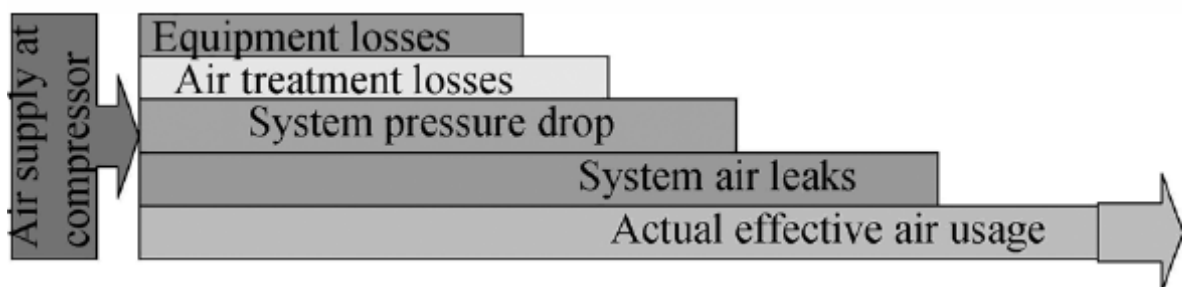


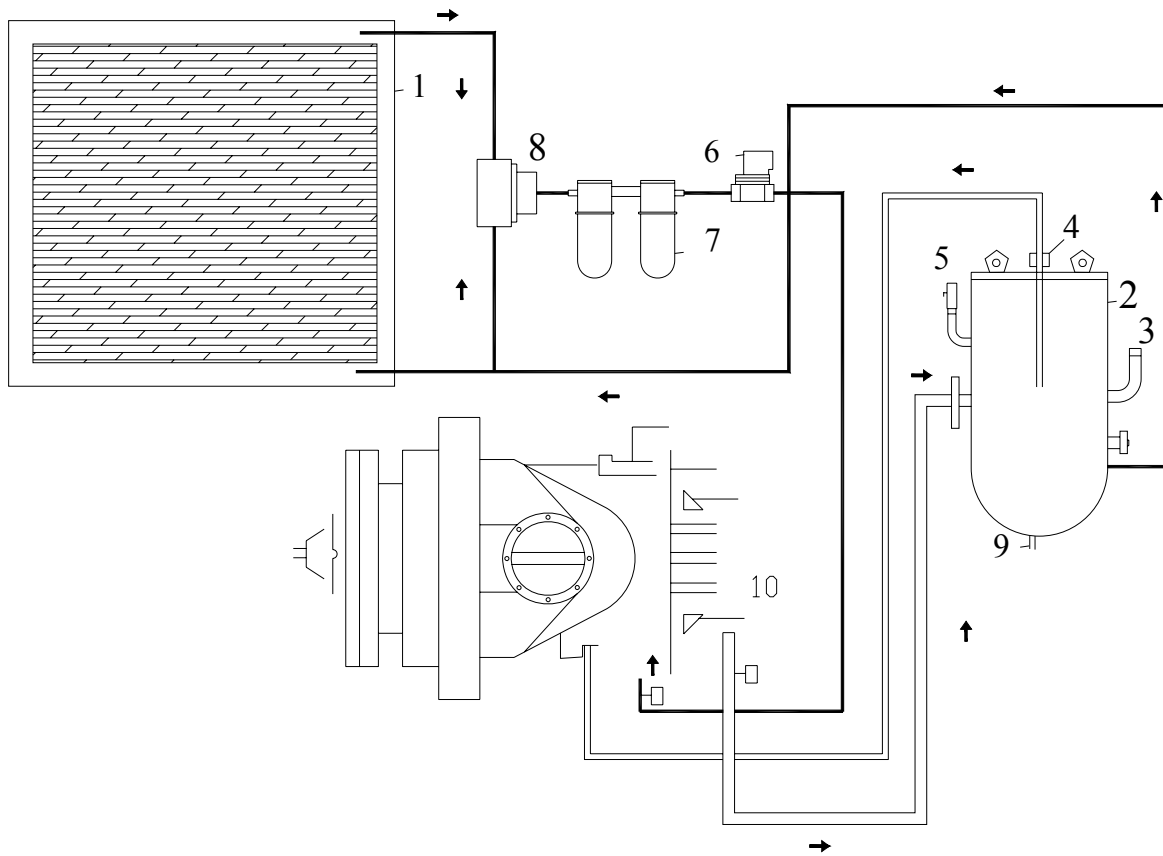
Figure 6.6 Losses in Air Compressor Systems

6.4.3 Compressed Air System Components

Compressed air systems consist of the following major components: intake air filters, inter-stage coolers, after-coolers, air dryers, moisture drain traps, receivers, piping network, filters, regulators, and lubricators. Intake air filters prevent dust from entering the compressor. Dust causes sticking valves, scoured cylinders, excessive wear, etc. Inter-stage coolers reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency. They are normally water-cooled. After-coolers work to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger. The traces of moisture remaining after the application of after-coolers are removed using air dryers, as air for instruments and pneumatic equipment has to be free of any moisture. The moisture is removed using adsorbents like silica gel/activated carbon, refrigerant dryers, or heat from compression dryers. Moisture drain traps are used for removal of moisture in the compressed air. These traps resemble steam traps. The types of traps used include manual drain cocks, timer-based automatic

drain valves, etc. Air receivers are provided for storage and smoothening of pulsating air output, reducing variations in pressure of air from the compressor.

One of the major electrical energy utilizing equipment of the company is air compressor with its motor. The standard compressor is designed to operate in ambient range of 1.7°C to 46°C . The standard maximum temperature of 46°C is applicable up to an elevation of 1000m above sea level. Above this altitude significant reduction in ambient temperature are required if a standard motor is to be used.



1. Cooler 2. Separator tank 3. Filter plug 4. Orifice & Screen 5. Safety valves
 6. Coolant stop valve 7. Coolant filter 8. Thermostatic valve 9. Drain valve
 10. Thermistor

Figure 6.7 Schematic Diagram of Company Screw Type Air Compressor

Compression in the screw type air compressor is created by the meshing of two (male & female) helical rotors. The air or coolant mixture discharge from the compressor into the

separation system. This system removes all but a few PPM of the coolant from the discharge air. The coolant is returned to the cooling system and the air passes to the after cooler and out of the compressor through the moisture separator. Air pulled into the compressor by the cooling fan and is pushed through the coolers.

By cooling the discharge air and passing it through the separator, much of the water vapour which is naturally present in the air can be removed. The coolant system consists of a sump, cooler, thermostatic valve and a filter. When the unit is operating, the coolant is pressurized and forced to the compressor bearings. The compressor load control system is automatic on-off line. The compressor will operate to maintain a set discharge line pressure and is provide with an auto restart system for use in plant where the air demand varies widely.

The company use screw type air-cooled air compressor and its motor is a three-phase AC induction.

Measurement data on compressed air system is not collected due to the company installed a new compressor and rejected the old compressor.

CHAPTER 7

7 ENERGY ACTION PLAN

7.1 Introduction

Improving energy efficiency in glass manufacturing should be approached from several directions. A strong, corporate-wide energy management program is essential. Ideally, such a program would include facility, operations, environmental, health, and safety, and management personnel. Energy efficiency improvements to cross-cutting technologies, such as the use of energy-efficient motors and the optimization of compressed air systems, present well-documented opportunities for energy savings. Optimizing system design and operations, such as maximizing process waste heat recovery, can also lead to significant reductions in energy use. In addition, production processes can often be fine-tuned to produce similar savings.

To improve the energy efficiency and thereby the productivity and competitiveness of Addis Ababa Bottle & Glass Share Company 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.

1 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.

2 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 company level with small investment and are generally of low individual cost.

3 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.

7.2 Energy Management Systems and Programs

Although technological changes in equipment conserve energy, changes in staff behavior and attitude can also have a great impact. Energy efficiency training programs can help a company's staff incorporate energy efficiency practices into their day-to-day work routines. Personnel at all levels should be aware of energy use and company objectives for energy efficiency improvement. Energy efficiency programs with regular feedback on staff behavior, such as reward systems, have had the best results. Though changes in staff behavior (such as switching off lights or closing windows and doors) often save only small amounts of energy at one time, taken continuously over longer periods they can have a much greater effect than more costly technological improvements.

Establishing formal management structures and systems for managing energy that focus on continuous improvement are important strategies for helping companies manage energy use and implement energy efficiency measures. Improving energy efficiency in glass manufacturing should be approached from several directions. A strong, corporate-wide energy management program is essential. Ideally, such a program would include facility, operations, environmental, health, and safety, and management personnel. Energy efficiency improvements to cross-cutting technologies, such as the use of energy-efficient motors and the optimization of compressed air systems, present well-documented opportunities for energy savings. Optimizing system design and operations, such as maximizing process waste heat recovery, can also lead to significant reductions in energy use. In addition, production processes can often be fine-tuned to produce similar savings.

Energy efficiency is extremely important to all organisations, especially those that are energy intensive.

The four vital requirements for a successful energy management is shown in Figure 8.1. Any successful energy management programme within an organisation needs the total support of top management. Hence, top management support is the key requirement for success. Top management should give energy efficiency equal importance in their corporate objectives as manpower, raw materials, production and sales. The other important requirements are a well charted strategy plan, an effective monitoring system and adequate technical ability for analysing and implementing energy saving options.



Figure 7.1 The four Pillars of Successful Energy Management

7.2.1 Energy management programs

Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy efficiency improvements.

Energy efficiency does not happen on its own. A strong energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs also help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Furthermore, without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational Cross-cutting technologies are defined as equipment that is commonly used, such as furnace, pumps, motors, compressed air systems, and lighting.

A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place

to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined in Appendix B.

Progress evaluation involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communications program and seeking recognition for accomplishments are also critical steps. Strong communication and receiving recognition help to build support and momentum for future activities.

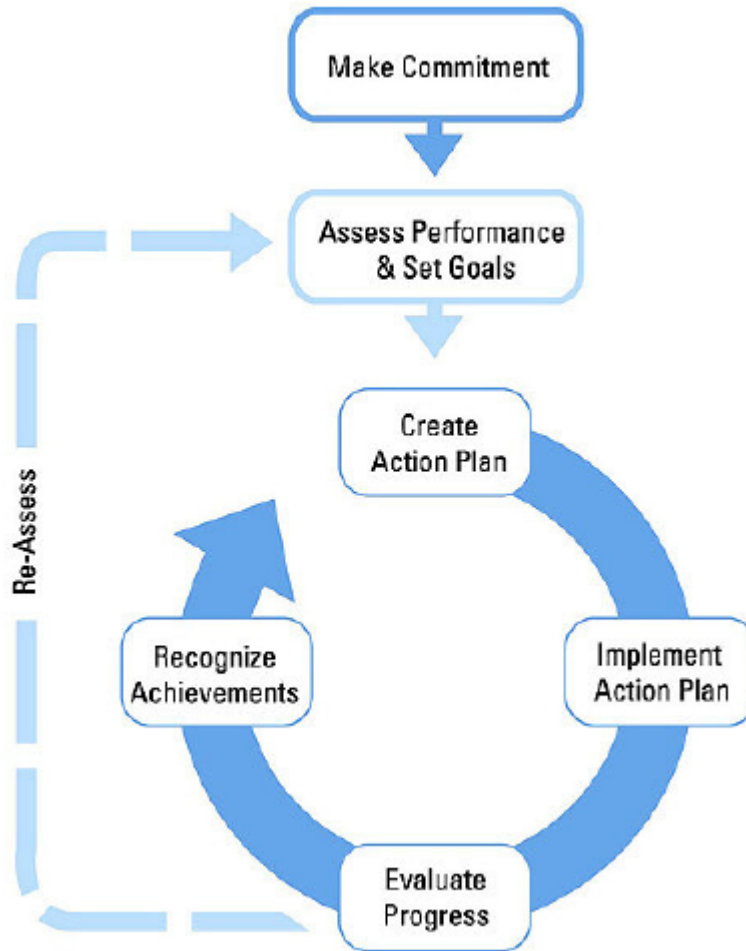


Figure 7.2 Main Elements of a Strategic Energy Management Program

An important step towards the development and successful implementation of a corporate energy management program is the formation of “energy teams”. Successful programs in many companies have demonstrated the benefits of forming teams consisting of people from various plants and departments of the company to bring together the wide expertise needed for the successful development of energy efficiency programs and projects within a company or at a site.

As discussed above, internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Some utility companies work together with industrial clients to achieve energy savings. In these cases, utility personnel work directly with the company onsite. Furthermore, programs to

support energy-efficiency improvements at industrial sites exist. Both the federal government and various states offer dedicated programs.

7.2.2 Energy Monitoring and Control Systems

The use of energy monitoring and process control systems can play an important role in energy management and in reducing energy use. These may include sub-metering, monitoring, and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality and consistency, optimize process operations, and improve production budgeting.

Monitoring and targeting systems can enable companies to achieve about 10% reduction in energy without any investment. Further improvements through improved data quality, improved time correspondence of data, and increased frequency or locations analyzed may improve the monitoring system and lead to further savings. For process control systems, energy and cost savings are typically around 5% or more for many industrial applications (but can vary greatly from plant to plant).

7.3 Energy Action Team

Energy action team at the company must be established to supervise, monitor and report the energy utilization of the company. 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 company. The energy action plan of the recommended energy conservation opportunities for post audit phase analysis is prepared in Table 8.1

7.4 Maintenance

Maintenance is a critical part of a facility's operation. Properly maintained equipment and processes are necessary to keep the facility functioning at its optimum capability. Unfortunately,

the maintenance program is often one of the first victims of any cost-cutting effort. Generally, preventive or scheduled maintenance is cut back or eliminated.

Then the maintenance effort is directed more toward repair and replacement than toward keeping the equipment running most efficiently. Maintenance should be an integral part of any energy management program. Maintenance keeps equipment from failing, helps keep energy costs within reason, helps prevent excess capital expenditures, contributes to the quality of a product, and is frequently necessary for safety.

Table 7.1 The Energy Action Plan

S.N ^o	Recommended ECO _s	Responsible body	Energy Action Term
1	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
2	Maintaining optimum operating temperature of Furnace	Mechanical crews	Short term
3	Clean the melting furnace room from dirt	Process crews	Short term
4	Control the excess air and damper position	Mechanical crews	Long term
5	Change the insulation of refractory brick lines by ceramic fibber	Mechanical crews	Long term
6	Regularly clean the transformer fins from dirty.	Electrical crews	Short term
7	Removes shrubs around the transformer area	Process crews	Short term
8	Install power measuring instrument for major electric appliance systems	Electrical & Instrumentation crews	Medium term
9	Hang the fluorescent lamps to the proper place.	Electrical crews	Short term
10	Replace old and incandescent lamp	Electrical crews	Medium term
11	Control compressed air distribution line valves	All members	Short term

	open when it is needed		
12	Regularly clean the electric motors from dirt	Electrical crews & Process crews	Short term
13	Replace the low power factor motors with high power factor when they fails	Electrical crews & Process crews	Long term
14	Replace the oversized and under loaded motors with appropriate sized motors	All members	Long term
15	Regularly remove scale deposit from the outlet of the furnace	Mechanical crews & Process crews	Short term
16	Periodically removes soot from the furnace	Mechanical crews	Short term
17	Regularly remove scale deposit from the hearth of melting furnace.	Mechanical crews	Short term
18	Keeping the required pressure in the furnace within the recommended range	Mechanical crews	Medium term
19	Install a new recuperator for recover heat from flue gas	Mechanical crews	Long term
20	Clean the pumps for dirt	Process crews	Short term
21	Seal the pumps properly to avoid leakage	Mechanical crews	Short term
22	Check proper functioning of the burner once in a shift and make correct action	Mechanical crews	Short term
23	Calibrate instruments mounted on the furnace body	Instrumentation crews	Short term

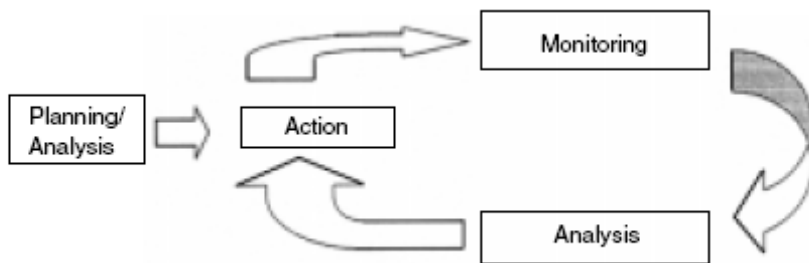


Figure 7.3 Overview of the Maintenance Energy Management Function

7.5 Steps For Process Improvement

The same order of change is appropriate for process energy management, the analyst must understand the entire system and the cascading impacts that changes might effect. In terms of energy management, examples of the preceding changes include the following:

- ✓ ***Change equipment, person, place, or sequence.*** Equipment changes can offer substantial energy savings as the newer equipment may be more energy efficient. For example, new electric welders are considerably more energy efficient than older ones. Changing persons, place, or sequences can offer energy savings as the person may be more skillful, the place more appropriate, and the sequence better in terms of energy consumption. For example, bringing rework back to the person with the skill and to the place with the correct equipment can save energy.
- ✓ **Improve.** Most energy management work today involves improvement in how energy is used in the process because the capital expenditure required is often minimized. Examples include reducing excess air for combustion to a minimum, reducing temperatures to the minimum required.

7.6 Top Management Commitment and Support

Top management shall make a commitment to allocate manpower and funds to achieve continuous improvement. To establish the energy management programme, leading organizations appoint energy manager, form a dedicated energy team and institute an energy policy.

➤ **Appoint an Energy Manager**

The tasks of energy manger are setting goals, tracking progress, and promoting the energy management program. An Energy Manager helps an organization achieve its goals by establishing energy performance as a core value.

The Energy Manager is not always an expert in energy and technical systems. Successful Energy Manager understands how energy management helps the organization achieve its financial and environmental goals and objectives. Depending on the size of the organization, the Energy Manager role can be a full-time position or an addition to other responsibilities.

➤ **Location of Energy Manager**

The energy management function, whether vested in one “energy manager or coordinator” or distributed among a number of middle managers, usually resides somewhere in the organization between senior management and those who control the end-use of energy.

Exactly how and where that function is placed is a decision that needs to be made in view of the existing organisational structure.

➤ **Energy Manager: Responsibilities**

- Prepare an annual activity plan and present to management concerning financially attractive investments to reduce energy costs
- Establish an energy conservation cell within the firm with management’s consent about the mandate and task of the cell.
- Initiate activities to improve monitoring and process control to reduce energy costs.
- Analyze equipment performance with respect to energy efficiency
- Ensure proper functioning and calibration of instrumentation required to assess level of energy consumption directly or indirectly.
- Prepare information material and conduct internal workshops about the topic for other staff.
- Improve disaggregating of energy consumption data down to shop level or profit centre of a company.
- Establish a methodology how to accurately calculate the specific energy consumption of various products/services or activity of the company.
- Develop and manage training programme for energy efficiency at operating levels.
- Co-ordinate nomination of management personnel to external programs.
- Create knowledge bank on sect-oral, national and inter-national development on energy efficiency technology and management system and information denomination
- Develop integrated system of energy efficiency and environmental up gradation.

- Co-ordinate implementation of energy audit/efficiency improvement projects through external agencies.
- Establish and/or participate in information exchange with other energy managers of the same sector through association.

CHAPTER 8

8 CONCLUSION, RECOMMENDATION AND FUTURE WORK

8.1 Conclusion

Glass manufacturing consumes a considerable amount of energy. Energy efficiency improvement is an important way to reduce costs and to increase predictable earnings, especially in times of high energy price volatility.

The concept of industrial energy audit has been analyzed in this research work as a case study at Addis Ababa Bottle & Glass Company. This thesis discussed the energy related problem of the company and attaining the thesis research objectives. The major problem of the company in connection with energy cited in the thesis proposal were unknown air –fuel ratios, most of the motors ran with unknown load factor and unknown combustion and furnace efficiency etc. These were well addressed by the paper as discussed below. The company uses thermal and electric energy to produce container glass. The energy consumption of the company is higher than the energy consumption of various countries with best industry practice (benchmark), for instant AABGC company consumes 7064.52kJ of fuel energy and 55421.43kJ of electric energy to produce one kilogram of container glass but the benchmark factories for instant USA in 1993 G.C consumes 5760.42 kJ of fuel energy and 42,000.54kJ of electric energy to produce one kilogram of container glass.

The energy consuming systems of the company were examined for their energy performance. The inspection identified large numbers of no/low cost energy conservation opportunities (ECOs) and the melting furnace and the motors with its prime movers of the company were found to be the major energy consuming systems.

The standard chemical reaction of furnace oil burning on mass basis is developed and the theoretical air-fuel ratio was found to be $13.92 \frac{\text{kg of air}}{\text{kg fuel}}$. A standard procedure to determine the actual air-fuel ratios of the furnace is developed based on the percent oxygen content of the flue gases and the value of the actual air-fuel ratio of the furnace was found to be $32.85 \frac{\text{kg of air}}{\text{kg fuel}}$.

A standard mass analysis of the dry flue gases constituents of the melting furnace is produced to help estimates the stack loss from the furnace. And the load factor helps to estimate the actual input electric energy of each motor.

The energy efficiency of the melting furnace of the company is found 42%. This efficiency is less than the expected performance of the melting furnace, which is equal to 66% [4]. The main causes that contribute to the significant drop in efficiency of the melting furnace are the energy loss due to: dry flue gas loss, hydrogen in furnace oil, moisture in fuel oil and melting furnace surface loss and unaccounted loss. The energy loss due to furnace oil hydrogen content and moisture content in the fuel are unavoidable losses. But energy loss due to dry flue gases & melting furnace surface energy loss can be reduced. Hence minimizing these energy losses are considered as energy conservation opportunities that could significantly improve the energy efficiency of the melting furnace.

The following are technically and economically feasible ECOs that play crucial role in improving the melting furnace efficiency:

The overall energy efficiency company motors with its prime movers are ranges 12% - 20%. Which are very small as compare to the recommended value of 51%. Therefore, the audit results and the method developed helps the company to have a clear picture of its energy usage, energy efficiency and be energy self-sufficient and competent container glass manufactures. In addition, the energy audit analysis methods and some of the energy conservation opportunities could be directly copied to other branch container glass producer factories and to any energy consuming systems similar to that of Addis Ababa Bottle & Glass Share Company with slight modifications.

8.2 Recommendation

Using a lot of different data collected from the control panels of the melting furnace & air compressor, direct measuring using portable measuring instruments and company record books the energy efficiency of the company was performed. Therefore, the following recommendations are made based on the study that has been conducted.

- Installing recuperative systems & in recuperative systems, heat is continuously transferred from the exhaust gases to the combustion air in a heat exchanger. Excess heat in the off-gas stream of recuperative can be used to generate heat in a waste-heat recovery furnace (for example for to preheat cullet, combustion air & furnace oil.
- Improved refractory materials for the construction of outside the crown and the basin allow for higher operating temperatures (and thereby better insulation) while being less prone to corrosion. To improve energy efficiency and achieve higher flame temperatures.

- There should be a responsible section in the company to supervise, monitor and report the energy utilization of the company. The tasks performed by this section includes; assess performance and set goals, look for any ECOs, formulate action plans for energy management opportunities, coordinate the implementation of the action plan, supervise and control the implementation, evaluate and report performance.

- Much more favorable is the situation where the electrodes are placed vertically through the bottom of the tank, because in this case the hot glass melt can rise free and unhindered to the surface. This improves the convection current, which results in better mixing, homogenizing and good decolourising. Because of the vertical placement of the electrodes, the upward movement of the intensely heated glass near the electrodes is accelerated and the danger of overheating the glass near the electrodes is also limited.

8.3 Future Work

This case study the need for further investigations in trying to assess other energy consuming equipments and the company to analysis its energy efficiency on daily basis it is important to develop a computer program that could perform the energy efficiency calculation.

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Appendix A
Company Energy and Material Data

Billing Period (E.C)	Fuel Consumption (litre)	Electricity Consumption (kWh)	Raw material Consumption (kg)	Container glass Production (kg)
Sep-01		751102.82	802020	538485
Oct-01		574532.99	952970	508825
Nov-01		736252.35	910000	569235
Dec-01		662000.02	737030	631140
Jan-01		575018.71	957740	512720
Feb-01		780803.76	837390	388590
Mar-01		647149.55	1003570	591820
Apr-01		600476.65	973340	651730
May-01		816869.18	8917110	450670
Jun-01				
Jyl-01	16349.54	621691.61	306075	582780
Aug-01	1463.49	808383.19	802020	582690
Total	17813.03	7,574,280.83	17,199,265	6,008,685

Appendix B: Basic Energy Efficiency Actions for Company Personnel

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement.

- ❖ Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.
- ❖ Switch off unnecessary lights; rely on day lighting whenever possible.
- ❖ Look for unoccupied areas being heated or cooled, and switch off heating or cooling.
- ❖ Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.
- ❖ Check to make sure the pressure and temperature of equipment is not set too high.
- ❖ Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.
- ❖ Carry out regular maintenance of energy-consuming equipment.
- ❖ Ensure that the insulation on process heating equipment is effective.

Appendix C

Specification of Major Energy Consuming Systems of the Company

A. Specification of the Melting Furnace

- Types of the melting furnace is electric boosting continuous melting furnace
- Constructed in 2001
- The capacity of melting furnace is 30 ton / hr
- Melting temperature 1345 °c
- Hexagonal in shape, length of the side=2m, height=3.75m
- Used fuel oil and electricity
- Oil is pre heated temperature 80 °c

B. Fuel oil pump motor

- Made in Italy
- Type FCA-80A-4
- Serial No 08031747
- Capacity 0.55kW, Frequency 50 Hz, Voltage 380v
- $\text{Cos } \phi = 0.75$

C. Water pump motor

- ❖ Made in Italy
- ❖ Type CM40-250A
- ❖ Capacity 15 kW, Frequency 50 Hz, Voltage 380v

D. Specification of the Electric Motors

The company uses a total of 47 motors excluding the stand by motors, to accomplish container glass production process. These motors have different operating parameters these are:

- Output power vary from 90 kW to 0.55 kW
- Current consumption vary from 152 A to 1.25 A
- Voltage consumption is similar to all motors = 380 V
- Power factor vary from 0.85 to 0.75
- Operating hours vary from 800 to 880 hours per year

- Efficiency varies from 80 to 60

E. Air compressor specification

- ✓ Compressor screw type PA 315MU- π
- ✓ Made in United Kingdom
- ✓ Serial number 503774BL001
- ✓ Manufacturing year 2005
- ✓ Maximum pressure 7 bar
- ✓ Capacity 288Kw
- ✓ Pressure vessel volume 8m³
- ✓ Time taken to fill pressure vessel volume 200 sec

Appendix D
Questionnaire on Major Energy Consuming Systems

Furnace

Is a program to analyze to flue gas for proper air / fuel ratio ?

What is the measured O₂ content and temperature of the flue gas?

Are the furnace wall insulate? 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 company?

Is the company used by highly efficient pumps?

Are there pumps in which there is excessive flow? Which are they?

Cooling tower

Do the electrode 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

