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CENTER OF ENERGY TECHNOLOGY

ENERGY AUDIT OF AMBO MINERAL WATER FACTORY

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY, AAiT FOR PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTERS OF SCIENCE DEGREE IN ENERGY TECHNOLOGY

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ABSTRACT

Ambo Mineral water factory is one of energy consuming factories in this country. In the factory, the thermal energy developed by the boiler goes to bottle washer and energy from electricity is used to power electrically driven equipments: electric motors and their driving systems, and lighting. According to 2018(G.C) energy bill data, the factory paid for both thermal energy (oil) and electric energy 5,953,395.00 Birr and 1,008,685.00 Birr respectively. The energy consuming systems of the factory such as electric motors, boilers, air compressors, water pumps and steam distribution systems were audited. To perform the energy audit of these major energy consuming systems, different data (21-months, October,2017 to June, 2019 GC) were collected and analyzed by using portable instruments, the instruments installed on systems, nameplate, referring factory log sheet with the gross calorific value of 44,800kJ/kg of diesel oil. From the detail energy audit, by replacing the existing electric motors and water pumps annual energy cost of around 46,000birr and 128,700birr can be saved respectively. The energy audit of the boiler indicated that, its overall efficiency was 72.2% with possible energy conservation measures of repairing feed water treatment plant(about 267,800Birr can be saved annually) and insulating boiler surface(26,300birr can be saved annually). Finally, the energy audit on steam distribution lines indicated as around 71,700 birr can be saved annually.

ACRONYMS/ ABBREVIATIONS

AMWF……………………………..…Ambo Mineral Water factory

ECOs………………….……………..Energy conservation Opportunities

EEU…………………….……………Ethiopian Electric Utility

ETB……………………….………..Ethiopian Birr

GCV………………………...……..Gross Calorific Value

h ……………………………..……Enthalpy

kVA…………………………………..Kilovolt Ampere

kVAr……………………..……….. Kilovolt Ampere Reactive

kW…………………………..……..Kilowatt

kWh……………………..…..………..Kilowatt-hour

L……………………......................Liter

MJ…………………………………....Mega Jules

NaCl………………………………....Sodium Chloride

SO_2…………………………………..Sulphur dioxide

T……………………………………Temperature

Q……………………………………..Heat energy

γA ……………………………...…Humidity factor

η …………………………………..…Efficiency

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CHAPTER 1

1. INTRODUCTION

Energy efficiency is important both at company and national level. For companies, it improves profitability. For nations, it leads use of improved national resources, reduces energy imports, conservation of foreign exchange, reduces capital requirements for new energy production facilities, and decreases environmental pollution due energy use and production.

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 programme. It is 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. In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labor 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. It 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. Its primary objective is to determine ways to reduce energy consumption per unit of product output or to lower operating costs.

Improving energy efficiency at the plant could be approached from several directions. Firstly, plants use energy for equipment such as motors, lightings, pump, compressors, boilers, etc. These important utilities require regular maintenances, good operation and replacement when necessary. Thus, a critical element of the plants energy management involves the efficient control of crosscutting equipments or utilities that powers the production process of the plant. A second important area is the proper and sufficient operation of the process. Process optimization and ensuring the most efficient technology is in place a key energy savings and cost savings in plant's operations. [5-6]

However, decrease in the energy efficiency results in increase in the energy consumption of the factory and other problems.

Thus, conducting energy audit to increase the energy efficiency has a great importance for proper functioning of the factory.

There are different high energy consuming industries such as sugar industries, mineral water industries, textile industries, cement industries, etc. Mineral water industries are one of the most energy intensive plants that use mostly electrical and fuel energies. The energy audit that has been done on several industries mostly occurs on the thermal energy efficiencies but the electrical energy has also major impact on the industries. [9]

Ambo mineral water factory is one of these industries which is found in Ambo, West Showa, in Oromia Regional State. The factory uses diesel oil and electric energy to generate thermal and electric energy in its production.

In this factory, boiler size, high steam leakages, running oversized motors etc. are the factors to be considered for energy efficiency of it.

Hence, it is worth to do this paper to assess the energy use of the Ambo Mineral Water factory, to identify and recommend energy conservation opportunities so that the energy costs of the factory can be reduced.

1.2 PROBLEM STATEMENT

Industries/Factories use electrical and thermal energy in machines or equipments like boilers, motors, pumps, compressors, furnaces, diesel generating engines, refrigerators, etc. But there are many problems in the industry sectors to efficiently use their energy. Due to this the factories are exposed to high energy bills, environmental problems, non-profitability and less competitiveness. [2-3].Industries, colleges and schools still find it difficult to make sure there is an efficient use of energy in its domain. [5][6]

In case of Ambo Mineral Water Factory the gaps (problems) identified were: Firstly, high cost of energy (the average monthly energy cost of Ambo Mineral Water Factory is 580,170birr). Secondly, the factory is running by boiler with designed capacity to produce a steam of 3ton / hr. at 12bar and 191.7 ^{O}C while the factory's need is about 2.1ton / hr., at 6.7- 7bar and average steam temperature of 165^{0}C. This shows that the boiler is oversized. Thirdly, as observed from the factory visit, there are significant steam leakages; most of the pumping systems and electric motors are operating at lower efficiency. Fourthly, the comparison on specific energy of Ambo Mineral Water Factory (AMWF) and the benchmark indicates that there is a significant difference between them. The average specific energy consumption of AMWF is 0.59MJ/L of Ambo mineral water while the average specific energy done on water bottling factory that uses electricity as a whole has international benchmark of around 0.25 MJ/ liters [7].

Thus, this research paper conducts energy audit of the factory and suggests better energy conservation opportunities and measures to improve the efficiency of the factory.

1.3 OBJECTIVE

1.3.1 General Objective

The general objective of this thesis research is to assess the energy use of the Ambo Mineral Water factory, to identify and recommend energy conservation opportunities and measures so that the energy costs of the factory may be reduced.

1.3.2 Specific Objectives

The specific objectives are:

- To study the production process flow of the factory.
- To identify the energy consuming equipments, machines and system of the factory
- To identify types of energies used,
- To assess the energy performance of the factory by conducting a detailed energy audit of energy wasting systems
- Identify energy conservation opportunities for the factory
- To conduct the technical and economic evaluation of the identified energy conservation opportunities
- To recommend possible energy saving measures and propose plan of action to Ambo Mineral Water Factory.

1.4 METHODOLOGY

In this thesis research different step by step methods have been utilized in order to achieve set objective**.**

1.4.1 Literature Review

Literature review has been conducted on the area of industrial energy consumption or use and efficiency related to bottled mineral water and beverage industries. Previous research case studies, related books, journals & guidelines have been reviewed in order to have a clear understanding of the subject matter.

1.4.2 Energy Audit Procedures

1.4.2.1 Energy Audit Phases

Step 1: Primary data gathering;

- Products/service of the facility, process flow diagram and identify major energy consuming systems of the factory

Step 2: Measurement

Step 3: Analysis; Energy/ mass balance and energy loss/waste analysis

Step 4: Identification and development of energy conservation opportunities (ECOS)

Step 5: Conduct cost benefit analysis: Technical and economic feasibility.

Step 6: Preparing and recommending the top management of the factory the prioritized promising ECOs for implementation.

1.4.2.2 Energy Audit Instruments

1. Electrical Measuring Instruments (Voltmeters): These are instruments for measuring major electrical parameters such as currents (Amps) and Voltages (Volts.)

2. Combustion analyzer: This instrument has in-built chemical cells which measure various gases such as O_2, CO, combustion efficiency, excess air *etc.* and temperature of the flue gas.

3. Contact thermometers: These are thermocouples which measures for example flue gas, hot water temperatures by insertion of probe into the stream.

4. Infrared Thermometer: This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. This instrument is useful for measuring hot spots in furnaces, surface temperatures etc.

5. Water flow meter: This contact flow measuring device measures water volumetric flow (m^3/s).

6. Local Control Panel (LCP): To measure the power, current and speed of motors.

1.5 ORGANIZATION OF THE THESIS

This thesis research paper is organized in to 8 chapters with the following details.

- ✓ Chapter 1: it discusses the need of conducting energy audit, the problem statement, and the general and specific objectives of the thesis research and the meaning of energy audit, types and methodology.
- ✓ Chapter 2: Presents the literature review.
- ✓ Chapter 3: Discusses brief introduction of Ambo Mineral Water Factory (AMWF) including: its foundation, location, structure of organization, employees, the utilities *etc*. and the main AMWF production process.
- ✓ Chapter 4: Deals with the factory energy bill, energy consumption patterns of the factory and specific energy of the factory.
- ✓ Chapter 5: Discusses about energy audit of electric motors of the factory
- ✓ Chapter 6: Deals with the performance of water pumps of AMW factory
- ✓ Chapter 7: Presents performance evaluation of air compressor in the factory
- ✓ Chapter 8:Breifly describe energy audit of boiler
- ✓ Chapter 9: Energy audit of steam distribution system (steam pipelines surfaces, steam leakage ,condensate and steam trap of the factory)
- ✓ Chapter 10: Gives short, medium and long term energy action plans for the factory, AMWF.
- ✓ Chapter 11: Presents the conclusions and recommendations for the particular factory and similar factories in this country.
- ✓ At the end of the paper reference and appendixes are also included.

CHAPTER 2

LITERATURE REVIEW

Energy audit is a pre-requisite to efficient energy management in the industry. It is a methodical way to investigate and analyze the energy utilization of any industry to ascertain areas where energy waste can occur and its use can be minimized. Boiler is a widely used steam generating system in industries and power plants. A significant portion of the world energy consumption is being used in boilers. A small improvement on the boiler efficiency will help to save a large amount of fossil fuels and to reduce CO2 emission. In general, the efficiency of boilers varies from 75% to 90%, so ways should be sought to minimize the resulting 10–25% energy losses in boilers [1].

Several types of applications (motors, boilers, compressors, furnaces, air-conditioning and lighting etc.) use energy in its different forms. An efficient use of these applications can reduce considerably the energy bill and CO emissions in industries. Some of the findings reveal that a bulk of electrical energy in the industry is wasted due to utilization of low efficient electric motors. The rounded electric motors further reduces the efficiency by about 3–7%, all there wound motor should be out rightly replaced with a super-efficient motor[2]. Improving energy efficiency in manufacturing can be considered as a pragmatic and an attractive solution, because it assists manufacturers to address the mentioned concerns as well as reducing their production cost, ultimately enhancing their competitiveness in the market.

Energy audit has been proved to be one of the most effective measures that are widely used to diagnose, analyze and improve energy use in the industrial and building sectors. Its concept has appeared just after the 1970’s oil crisis [3].It describes accurately the operation characteristics of end-use applications, identifies their related energy saving potential and proposes argued actions and measures to achieve these savings along with their economical profitability.

In addition to reduced energy costs, other non-energy benefits of making energy efficiency investments can go far beyond energy savings. For example: better working conditions, improved product quality and increased productivity, reduced cost of environmental compliance, raw material savings, reduced emissions, extended equipment life and reduced maintenance requirements [4-6].

Combustion air preheating is an alternative to feed water heating. In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 °C Even though the allowable limit in the stack is 400 ppm air free, the production of CO in the flue gasses should be kept below 100 ppm air free. The best option during this process is to shut-down or repair burner [17].

Even if the stack temperature should be lower, it should not be so low that water vapor in the exhaust condenses on the stack walls. It is important in fuels containing significant Sulphur as low temperature can lead to Sulphur dew point corrosion. If the stack temperature exceeds 200°C it is better to think waste heat recovery. The flue gas exit temperature from a boiler is usually maintained at a minimum of 200 °C, so that the Sulphur oxides in the flue gas do not condense and cause corrosion in heat transfer surfaces. An estimated 1% efficiency loss occurs with every 22 °C increase in stack temperature. High exit gas temperatures at normal excess air can result from a gradual build-up of gas-side or waterside deposits. Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits. The potential for energy saving depends on the type of boiler installed and the fuel used. For older model shell boilers, having temperature of 260 °C, an economizer could be used to reduce it to 200 °C, increasing the feed water temperature by 15 °C[38]. In the case of oil fired systems, CO with normal or high excess air indicates burner system problems and more frequent cause of incomplete combustion is the poor mixing of fuel and air at the burner.

The surface of the boiler lose heat to the surroundings as the external surfaces of a shell boiler are hotter than the surroundings and it depends on the surface area and the difference in temperature between the surface and the surroundings air. The heat loss from the boiler shell is normally a fixed energy loss, irrespective of the boiler output. With modern boiler designs, this may represent only 1.5% on the gross calorific value at full rating, but will increase to around 6%, if the boiler operates at only 25 percent output [39].

The potential savings from replacing a boiler depend on the anticipated change in overall efficiency. A change in a boiler can be financially attractive if the existing boiler is old and inefficient not capable of firing cheaper substitution fuel over or under-sized for present requirements not designed for ideal loading conditions.

CHAPTER 3

AMBO MINERAL WATER FACTORY OVERVIEW AND WATER BOTTLING PROCESS IN THE FCATORY

3.1 Overview of the Factory (Ambo Mineral Water Factory)

Ambo Mineral Water is a brand of naturally-carbonated bottled mineral water, sourced from the springs in Ambo Senkele, near the town of Ambo, in central Ethiopia. Ambo Mineral Water has been in business since 1930 and is sourced from a thermal mineral spring that has significant amounts of "natural calcium, magnesium, potassium, bicarbonates and carbon dioxide". The water is naturally carbonated by the carbon dioxide at the source. Ambo mineral Water factory is one of the largest mineral water bottler in the country established in 1930 and this also makes it the oldest bottler in the country. It is located about 120 km west of Addis Ababa. Mineral water plant obtained its name from the town Ambo where the factory was first established. The plant is located at an altitude of about 1970 meters above sea level. The bottling plant has a total area of about 90,000m^2. The working hours of the factory are 24 hours per day and 6 days per week with three shifts. The factory is structurally organized as Manufacturing Manager (top management) which includes (Human Resource, Production Department and Logistic Department).Human Resource consists security, Human Resource coordinator and time keeper. Quality control, process control, production and maintenance are under production department and logistic department has store and purchasing team. The factory has 255 permanent employees(152 males and 103 females) and 64 temporary workers(57 males and 7 females).Utilities used in the factory are water supply, air supply, electricity supply, steam supply and refrigeration plant.

Figure 3. 1Ambo Mineral Water Factory

3.2 Description of the Water Bottling Process in the Ambo Mineral Water Factory

i) Bore Hole: Bore holes were constructed at locations where aquifers (water bearing geologic formations) are both shallow and low-yielding. It is the source of the mineral water that goes to the production process, boiler and others. Submersible Pumps with motors (30kW and 15kW) are used to pump the mineral water from two bore holes to degassing tank.

ii)Water Treatment Plant: The main purpose of the water treatment is to prevent the formation of the various hard scale deposits caused by salts on the internal surface of the boiler as such deposits cause efficiency loses. Therefore to keep the water soft, a cation exchange resin bed together with a chemical solution doser is added in the feed water in the water treatment plant.

a) **Degassing Tank:** The mineral water pumped to degassing tank is purified from some gases in this tank. Then it is pumped to settling tanks.

b) Settling Tanks (Process and Softener Tanks): Dirt particles gain more weight and settle to the bottom of the water tank. The mud accumulated at the bottom of the tanker is removed using cleaning mechanism.

c) Filtering Tank: In this there are three tanks: Big sand tank, Carbon and Manganese filter tank. In sand tank filter the remaining suspensions are trapped by the sand. Then it is transferred to Manganese filter tank and then to carbon filter tank. In this, softening is used to avoid the calcium and the magnesium carbonates from the water. This water is pumped to processing activity (Ambo mineral water bottling).But for boiler, bottle washer, crate washer, cleaning, and other activities it has to be further purified by Sodium Chloride (NaCl). These tanks are cleaned by backwashing.

Figure 3. 2 Degassing Tank

Figure 3. 3 Filtering Tanks

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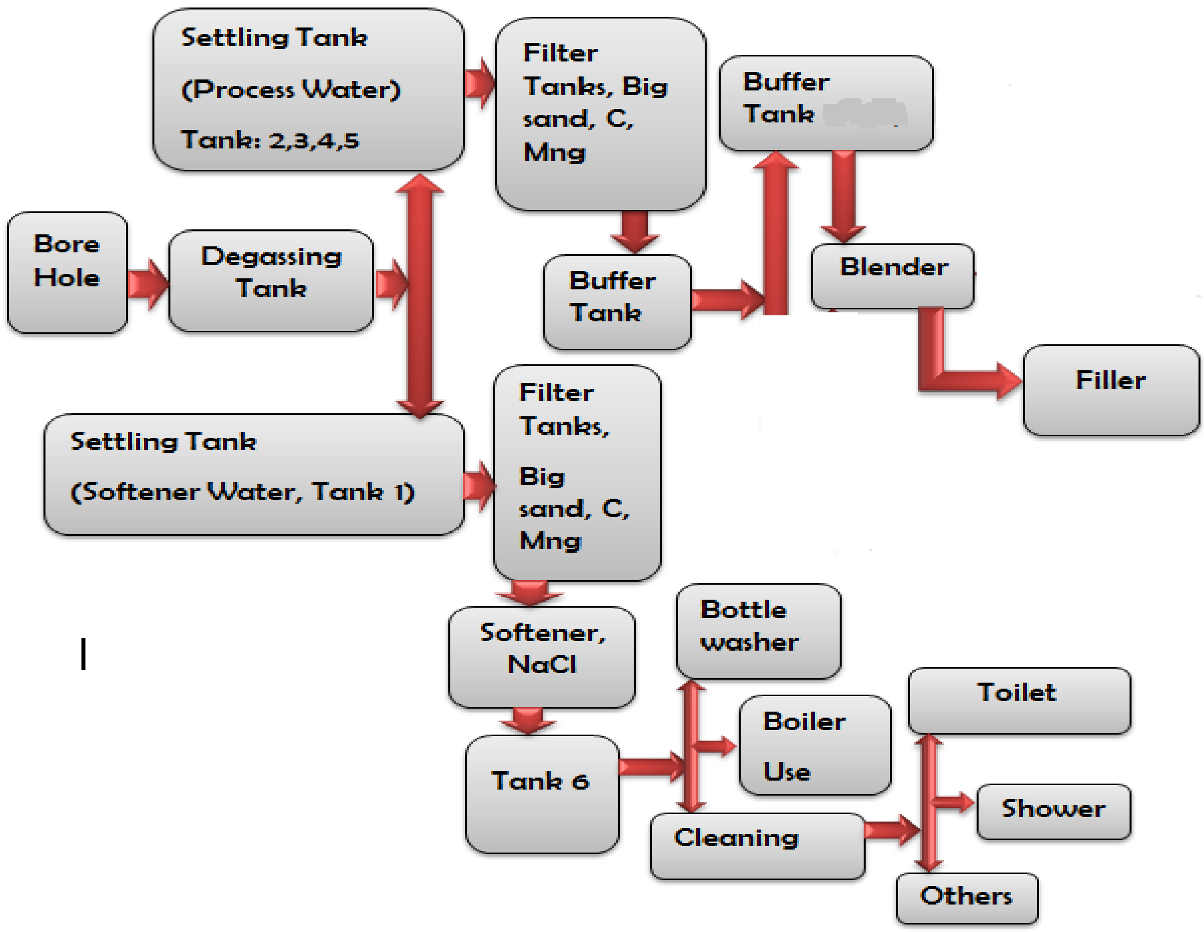

Figure 3. 4 Water Treatment/Process Flow Diagram

iii) Bottle and Crate Washer: Bottle/Crate washing machines are used to wash, sterilize and dry bottles/crates before being filled with water or taken to packing place. The steam that comes from steam line is given to inside cold water and mixed with caustic soda to clean the bottles. The bottle washer can wash about 32,000 bottles (475ml) per hour with 65^0C and 75^0C for each bath room. The average fresh water consumption and pressure for each bath are $12m^3/s$ and 3.1 bar respectively.

Figure 3.5 Bottle washer

iv) Conveyor Motor System: A conveyor system is a common piece of mechanical handling equipment that moves bottles from one location to another. In this factory the conveyor system starts from loading and end at unloading.

v) Mineral Water Filling

The bottle is pressed with filling part. In the lifting process, it checks whether there are bottles on bottleneck board. If there are bottles, the filling process is started; the bottle is filled with water. If there is no bottle, the valve remains closed. In this factory average of 24,000 bottles can be filled per hour.

Figure 3. 6 Filler

vi)Caser Machine(Packer): The extra ordinary case packaging machines are designed for automated packaging of bottles in their respective cases/crates. It works using air supplied from air plant.

Figure 3. 7 Packer

vii) Uncaser Machine(Unpacker): Are used for separating crate and bottles in the factory (for damage free unpacking of bottles from cases to bottle washer conveyor.)

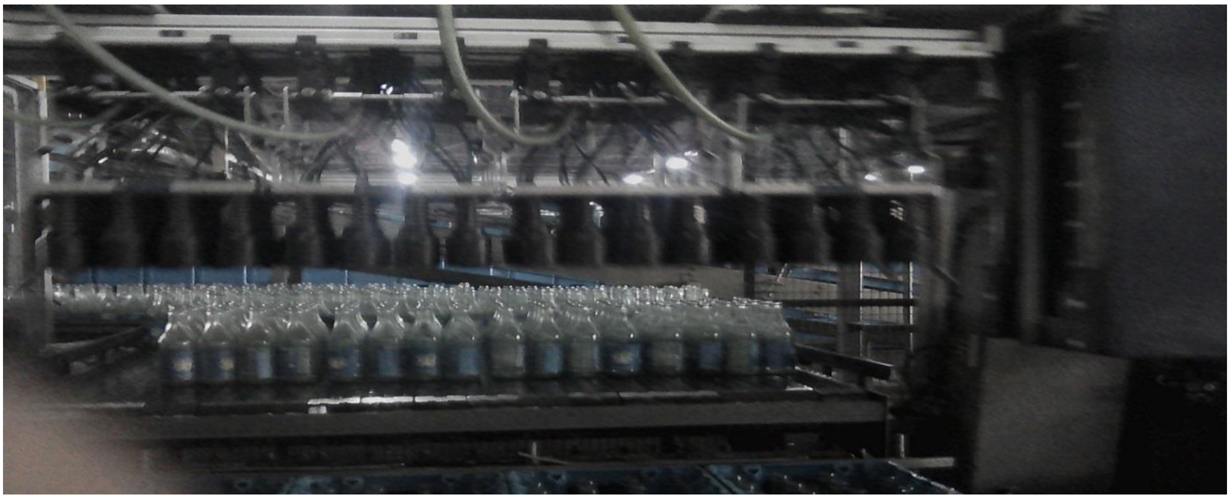

Figure 3. 8 Unpacker

viii) Air Compressor: Air compressor is used to supply air to process requirements, to operate pneumatic tools and equipments.

ix) Boiler: Boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes hot water or steam. The factory uses boiler type of firing tube and steam production of 3,000 kg/h, control panel (tension 400V/50Hz three-phases), and burner (fuel diesel oil).The boiler has feed water system, air system, steam system and fuel system. The feed water system provides water to the boiler and regulates it automatically. Steam is directed through a piping system to the different points of use. The fuel system includes all equipment used to provide fuel to generate the heat. The fuel given to the boiler is diesel oil. The designed capacity of the boiler is, to produce a steam at 12bar and 191.7 C^0 while it produces steam at temperature of 165C^0 a and 7bar.

Figure 3.9 Boiler

x)Chilling Plant: Here, refrigeration is used for the process of low temperature filling so that the dissolved CO_2 does not escape out of water.

There are other machines/equipments which are used for Labeling, capping, drying and date coding.

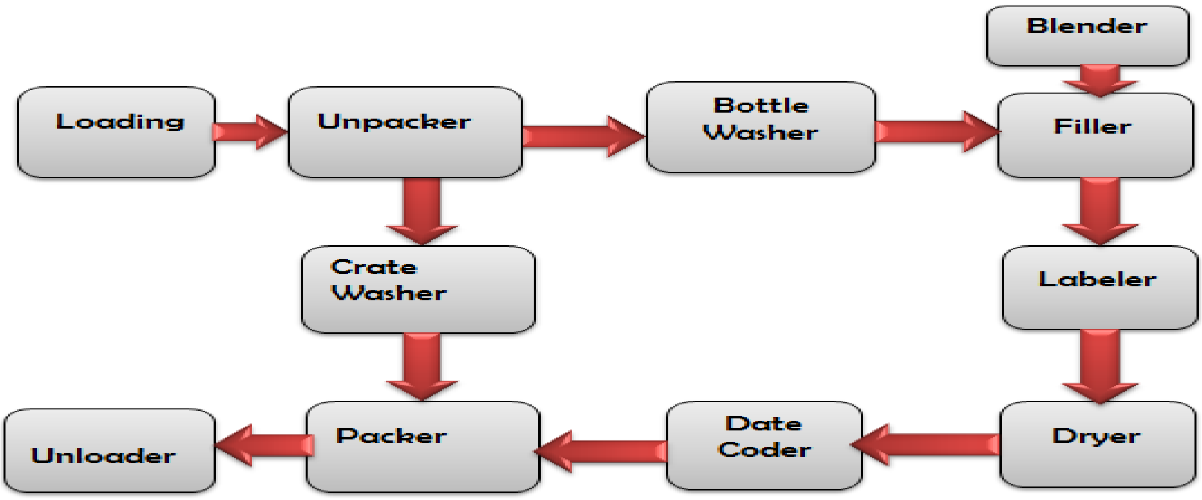

Figure 3.10 :The factory's Process Diagram

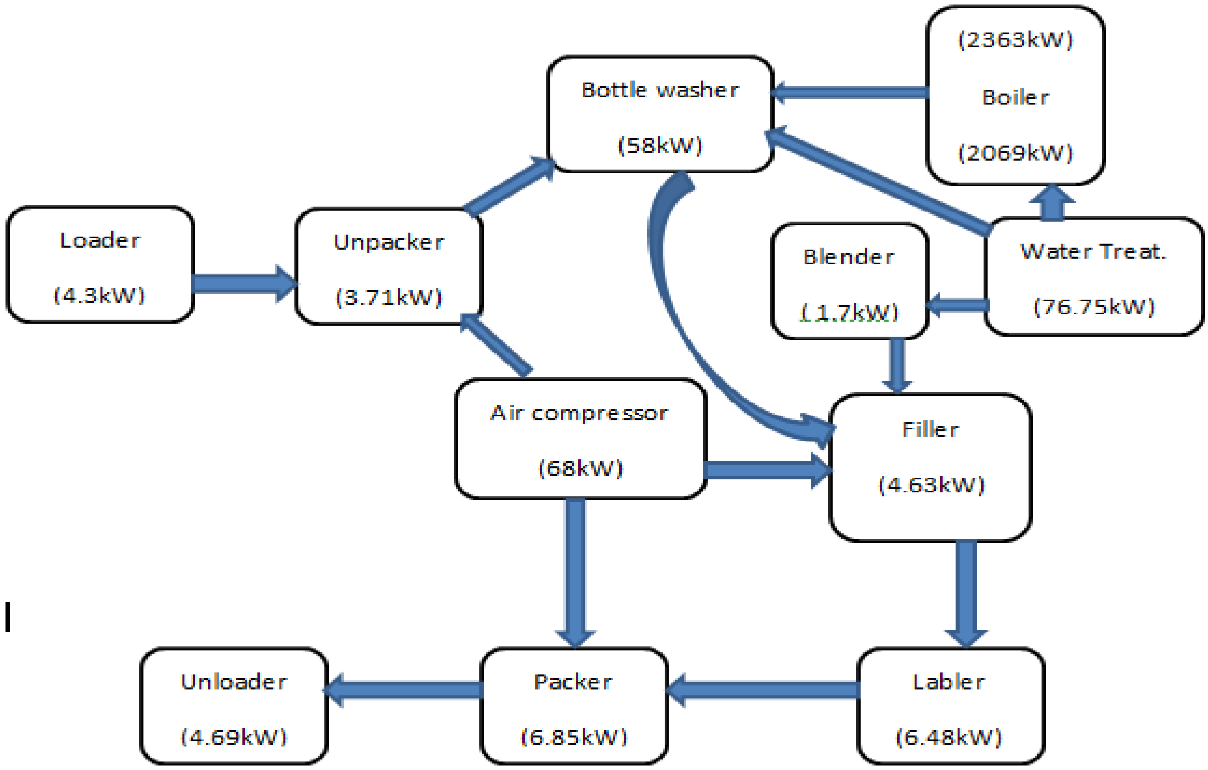

Figure 3.11 The factory's Energy Flow Diagram

From the figure 3 above equipments and their respective energy use are written. Most of the energy users are motors in the equipments. But the boiler consumes thermal energy which is from fuel oil. From the figure, energy intensive equipments are:

a) Boiler
b) Motors (embedded in each equipment)
c) Air Compressor
d) Pumps and their motors

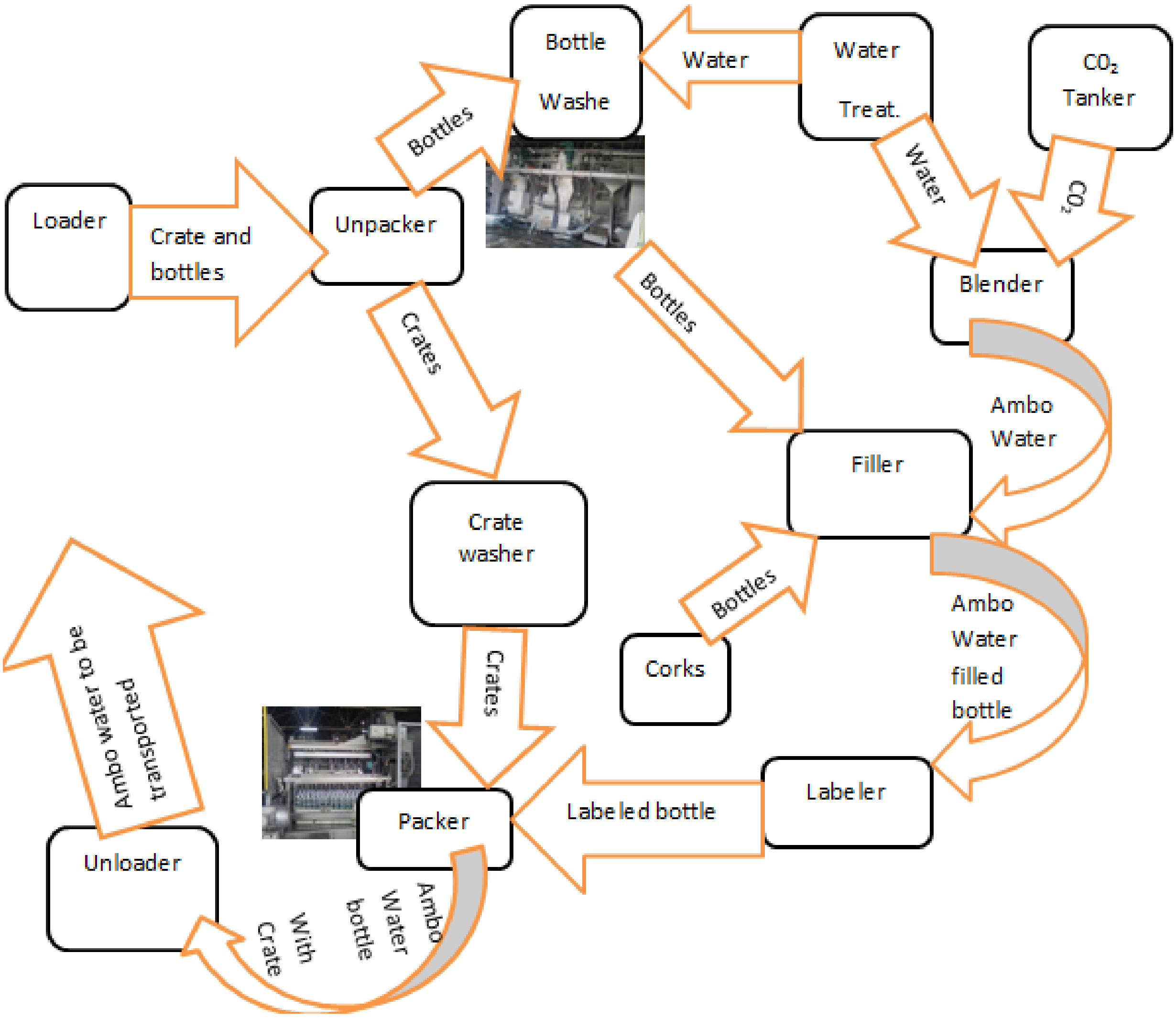

Figure 3.12 The factory's Material Flow Diagram

Figure 3.12 above shows the flow of materials from raw materials to the transportation of Ambo water to the market.

- The packed crates with bottles are loaded from outside to the loader and unpacked to bottles and crates.
- The washed bottles from bottle washer are taken to filler
- The treated water and carbon dioxide are mixed in in blender and transported to filler to be filled in bottles.
- The Ambo water filled bottles are crowned and taken to labeler and then date coded
- Finally the washed crates and bottles of Ambo water are packed by packer, unloaded and transported to the market.

CHAPTER 4

PRELIMINERY ENERGY AUDIT OF AMBO MINERAL WATER FACTORY

4.1 Introduction

Ambo Mineral water factory (AMWF) is one of energy consuming factories in this country. It uses diesel fuel oil to develop thermal energy and electricity to run the equipments. In this paper, energy audit has been done after power transformer and also the materials used from the transformer to points of use are almost properly selected and the amount of energy loss is relatively negligible. During the year 2018(G.C) the factory paid for both thermal energy (fuel oil) and electrical energy 5,953,395.00 Birr and 1,008,685.00 Birr respectively. To analyze the factory's energy consumption, to calculate average specific energy and to give conclusion the 21 months data (Oct. 1, 2017—June 1, 2019) energy (diesel oil in liter and electricity in kWh), and benchmark(average specific energy data of other factories) were collected and used. In this chapter, data collection of energy bill, production; data analysis through computation of energy cost, average specific energy; and finally remarks and conclusions are discussed.

4.2 Data Collection

In order to analyze the energy consumption of Ambo Mineral water factory a 21-months data of energy and mineral water production were collected from factory's production manager office.

4.2.1 Factory's Energy Bill and Material Consumption Data Collected

Ambo Mineral Water Factory energy bill (Electricity Consumption (kWh) and Liters of Fuel Consumption) and carbon-dioxide consumption data were collected and the data are tabulated in Appendix part.

4.2.2 Factory's Mineral Water production Data Collected

The factory's mineral water production (Ambo mineral water) from October, 2017 to June, 2019 (GC) was collected from Ambo Mineral Water Factory production office and the data is tabulated in Appendix.

4.3 Data Analysis of Factory's Energy Consumption and Production

In this section previously collected data (energy consumption and mineral water production data) are analyzed using the specific gravity of 0.845kg/L and the gross calorific value, GCV of 44,800KJ/kg of diesel oil.

4.3.1 Factory's Energy Cost

The energy cost of the factory is collected from the factory.

Fuel cost per month (ETB) =Liters of fuel (# L) used x cost of fuel (ETB per liter)……...…..4.1

Electricity cost per month (ETB) = Electric energy used (kWh)x Cost (ETB) per kWh…........4.2

Cost of fuel and electricity (flat multiplying factor) changes over time. For monthly Electricity and Fuel Cost of Ambo Mineral Water Factory (Oct 1, 2017—June 1, 2019), the flat multiplying factor deviates between 0.50ETB/kWh to 1.5 ETB/kWh and 18ETB/liter to 22ETB/liter of fuel.

Table 4 1 Electricity and Fuel Cost of Ambo Mineral Water Factory (Oct. 1, 2017—June 1, 2019)

Billing Period(G.C)	Electricity Cost data collected (ETB)	Fuel Cost data collected (ETB)	Electricity and Fuel Cost data collected (ETB)	Production of Ambo Mineral water(Liter)
October 1,2017	149,850.00	454,590.00	604,440.00	2,068,045.50
November 1,2017	129,600.00	396,465.00	526,065.00	2,319,463.00
December 1,2017	127,575.00	274,950.00	402,525.00	1,317,719.00
January 1,2018	110,266.94	590,340.00	700,606.94	2,759,522.00
February 1,2018	93,960.00	429,270.00	605,207.44	2,513,595.50
March 1,2018	65,418.37	308,940.00	374,358.37	1,637,695.50
April 1,2018	23,841.62	529,035.00	552,876.62	2,251,614.00
May 1,2018	90,358.54	721,605.00	811,963.54	3,062,695.50
June 1,2018	155,159.42	701,805.00	915,864.52	3,015,053.00
July 1,2018	86,508.00	378,345.00	464,853.00	1,954,767.50
August 1,2018	34,400.32	523,380.00	557,780.32	2,269,768.50
September 1,2018	96,120.00	551,415.00	647,535.00	2,168,090.00
October 1,2018	103,127.81	416,175.00	519,302.81	2,298,420.50
November 1,2018	76,839.67	415,485.00	492,324.67	2,396,878.50
December 1,2018	72,685.20	387,600.00	460,285.20	2,150,999.50
January 1,2019	223,219.42	571,260.00	794,479.42	3,114,964.50
February 1,2019	243,000.00	515,610.00	758,610.00	2,313,145.50
March 1,2019	150,187.50	624,435.00	774,622.50	2,182,872.00
April 1,2019	147,094.72	445,965.00	593,059.72	1,771,588.50
May 1,2019	151,162.81	525,945.00	677,107.81	3,197,776.00
June 1,2019	176,558.63	520,725.00	697,283.63	2,404,659.00

From the above Table 4.1, energy cost was relatively higher during the months of May, 2018 and June 2018 than the rest months. The high cost during these months was may be due to relatively more water production. On the other hand during the month of December, 2017 and March, 2018, the energy cost was lowest because the Ambo mineral water production was lowest.

4.3.2 Specific Energy of the Factory

Monthly specific energy consumption is defined as an average energy monthly needed to produce one liter of Ambo mineral water.

Monthly Specific Energy

of Fuel(MJ/liter of Ambo water**)** =[Gross calorific value of diesel(kJ/kg) x Density of diesel (kg/L) x monthly fuel used(L)] /1000[Monthly liters of Ambo mineral water

produced]……………………………………………………………………….…….4.3

Monthly Electric

Specific Energy((MJ/liter of Ambo water)= [Monthly Electricity Used (kWh)x 3600sec/h]/1000[Monthly liter of Ambo mineral Water produced]………………………...4.4

By using monthly electricity used (kWh), monthly liter of water produced and using the equation (4.3) & (4.4), the monthly Specific Energy of Electricity (MJ/liter of Ambo mineral water) and Specific Energy of Fuel (MJ/liter of water)of the factory is tabulated in table(4.2) below.

Table 4 2 The monthly Specific Energy Consumption of the factory

Billing Period	Specific Energy of Electricity (MJ/liter of Ambo water)	Specific Energy of Fuel (MJ/liter of Ambo water)	Specific Energy of Fuel and Electricity (MJ/liter of Ambo water)
October 1,2017	0.231	0.416	0.648
November 1,2017	0.178	0.323	0.502
December 1,2017	0.309	0.394	0.704
January 1,2018	0.248	0.404	0.653
February 1,2018	0.139	0.323	0.462
March 1,2018	0.236	0.357	0.593
April 1,2018	0.061	0.444	0.506
May 1,2018	0.114	0.446	0.560
June 1,2018	0.316	0.44	0.757
July 1,2018	0.089	0.366	0.455
August 1,2018	0.091	0.436	0.527
September 1,2018	0.089	0.481	0.571
October 1,2018	0.276	0.342	0.619
November 1,2018	0.189	0.328	0.517
December 1,2018	0.207	0.341	0.548
January 1,2019	0.229	0.347	0.576
February 1,2019	0.336	0.421	0.758
March 1,2019	0.22	0.472	0.692
April 1,2019	0.265	0.476	0.742
May 1,2019	0.151	0.311	0.462
June 1,2019	0.235	0.409	0.644

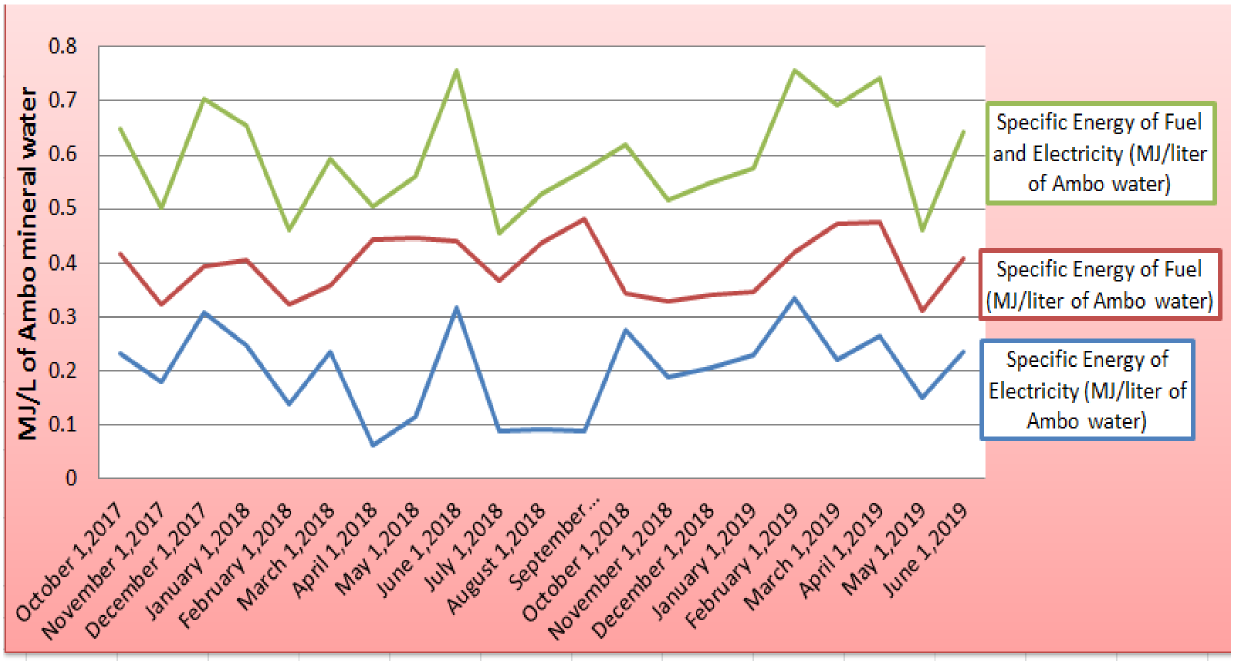

Figure 4 1 The monthly Specific Energy of the factory

4.3.3 Specific Energy Comparison of the Factory with Benchmark

The 21-months electric average specific energy of the factory varies between 0.061 MJ/liter of Ambo mineral water to 0.33MJ/liter of water with average of 0.20MJ/liter of water and fuel specific energy varies 0.31 MJ/liter of Ambo mineral water to 0.48MJ/liter of Ambo mineral water with average of 0.39MJ/liter of Ambo mineral water. The total average specific energy(fuel specific energy and electricity specific energy) of the factory is 0.59MJ/L of Ambo mineral water. The specific energy done on water bottling factory that uses electricity as a whole has international benchmark of around 0.25 MJ/ liters of water[7]. Hence, there is significant difference between the Ambo Mineral Water factory and the benchmark factory.

From the specific energy of factory calculated above the average specific energy of the factory is about 0.59MJ/L of Ambo mineral water which is equivalent to 590kJ/ L of Ambo mineral water. But (1kWh= 3600kJ) from this conversion 590kJ is equivalent to 0.164kWh and the Ethiopian Electric Utility decided that flat multiplying factor varies between 0.50ETB/kWh to 2ETB/kWh(EEU,2018).Then the AMWF is producing one liter of Ambo mineral water by about 0.33ETB and selling by about 10ETB(marketing office of AMWF).While the benchmark(250kJ/L of mineral water) [7]is producing 1liter of water by less than that of AMWF. The high variation that has been seen in electric specific energy shows that there were wastages in the electric motors of the factory.

4.4 Concluding Remark

As discussed above, the Ambo Mineral Water factory energy utilization (average specific energy of 0.59MJ/Liter of Ambo mineral water) is not efficient as compared to the international benchmark factories, which has average specific energy of 0.25MJ/Liter of mineral water [7]. The reason for this can be energy wastage of the factory. Therefore, conducting energy audit on its major energy systems is a wise choice.

CHAPTER 5

ENERGY AUDIT OF ELECTRIC MOTORS IN THE FACTORY

5.1 Introduction

Motors found everywhere from heating, ventilating and air conditioning systems to process drives to conveyor systems. The function of an electric motor is to convert electrical energy into mechanical energy. In Ambo Mineral Water factory, motors are used to drive conveyors, pumps, fans and an air compressor. The type of motors in the factory are; rated power of 0.55kW to 90kW,power factor of 0.80 to 0.81 and efficiency of 0.73 to 0.91.

To investigate the energy performance of motors, water pumps and air compressor and its motor different data were collected using their nameplates, voltmeter, clamper, fluid flow meter, control board displays, anemometer, meter, time watch, local control panel and by observation.

Many motors have been found with loading factor of less than 50%.By replacing these motors, annual energy cost of around 46,000birr/year can be saved. In this chapter energy usage performances of motors with their energy conservation opportunities and measures are discussed.

5.2 Motor Inspection and Data Collection

In order to compute the energy performance of factory's motors, different data of motors were collected by inspection and measurement.

5.2.1 Data Collected by Visual Inspection and Interviews

During the inspection of Ambo Mineral Water factory, the following data were collected by visual inspection and interviews.

- Rated power 0.55 kW to 90 kW,
- Rated power factor 0.80 to 0.81 and
- Rated efficiency 0.73 to 0.91
- The service time of the motors are 6 years to 13 years
- Operating hours of the motors varies between 450 hours to 6,336 hours per year.

5.2.2 Data Collected by Measurement

In addition to visual inspection and interviews, data needed for the computation of motor energy performance analysis were collected using instruments like voltmeter, clamper, local control panel, and control boards to measure input power to motor, current and voltages. The following table 5.1 contains type of motors, collected data of rated power(kW), Collected Data of Rated efficiency, measured input electric power(kW),calculated motor loading percentage which is the ratio of measured input electric power(kW) to collected data of rated power(kW),service year of motors and location of motors in the factory. The table contains motors with rating power of 0.75kW to 90kW.

Table 5 1 Type of motors, measured data, collected data and calculated data of motors

Type of Motor	Collected Data of Rated Power(kW)	Collected Data of Rated Eff.	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Sew-Euro Drive	0.75	73	0.28	37.3	13	Loader-Unpacker
Sew-Euro Drive	0.75	73	0.26	34.7	13	Loader-Unpacker
Siemens	1.1	77	0.58	52.7	6	Unpacker-Bottle Washer
Siemens	1.1	77	0.48	43.6	7	Unpacker-Bottle Washer
Siemens	1.1	77	0.55	50	6	Unpacker-Bottle Washer
Siemens	1.5	77	0.47	31.3	9	Unpacker-Bottle Washer
Siemens	1.5	77	0.56	37.3	9	Unpacker-Bottle Washer
Siemens	1.5	79	0.41	27.3	8	Washer-Filler
Siemens	1.5	79	0.36	24	8	Washer-Filler
Siemens	1.5	79	0.44	29.3	8	Washer-Filler
Siemens	1.5	79	0.48	32	13	Washer-Filler
Siemens	1.5	79	0.52	34.7	8	Washer-Filler
Siemens	1.5	79	0.58	38.7	8	Washer-Filler
Siemens	1.5	79	0.52	34.7	8	Washer-Filler
Siemens	1.5	79	0.48	32	8	Washer-Filler
Siemens	1.5	79	0.5	33.3	8	Washer-Filler
Siemens	1.1	77	0.48	43.6	8	Washer-Filler
Siemens	1.1	77	0.52	47.3	8	Washer-Filler
Siemens	1.1	77	0.55	50	8	Washer-Filler

Type of Motors	Collected Data of Rated Power(kW)	Collected Data of Rated Eff.	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Siemens	1.1	77	0.53	48.2	8	Washer-Filler
Siemens	1.1	77	0.5	45.5	8	Washer-Filler
Siemens	1.1	77	0.49	44.5	8	Washer-Filler
Siemens	1.1	77	0.48	43.6	8	Washer-Filler
Siemens	1.1	77	0.53	48.2	8	Washer-Filler
Siemens	1.1	77	0.48	43.6	8	Washer-Filler
Siemens	1.1	77	0.48	43.6	8	Washer-Filler
Siemens	1.1	77	0.53	48.2	8	Filler-Labler
Siemens	1.1	77	0.52	47.3	8	Filler-Labler
Siemens	1.1	77	0.47	42.7	7	Filler-Labler
Siemens	1.1	77	0.5	45.5	7	Filler-Labler
Siemens	1.1	77	0.52	47.3	7	Filler-Labler
Siemens	1.1	77	0.54	49.1	7	Filler-Labler
Siemens	1.1	77	0.5	45.5	7	Filler-Labler
Siemens	1.1	77	0.52	47.3	7	Filler-Labler
Siemens	1.1	77	0.49	44.5	7	Filler-Labler
Siemens	1.1	77	0.48	43.6	7	Filler-Labler
Sew-Euro Drive	1.1	77	0.23	20.9	7	Filler-Labler
Siemens	1.1	77	0.52	47.3	7	Filler-Labler
Siemens	1.1	77	0.49	44.5	7	Filler-Labler
Siemens	1.1	77	0.55	50	7	Filler-Labler
Siemens	1.5	77	0.53	35.3	7	Labler-Packer
Siemens	1.1	77	0.52	47.3	7	Labler-Packer
Siemens	1.1	77	0.53	48.2	7	Labler-Packer
Siemens	1.1	77	0.5	45.5	7	Labler-Packer
Siemens	1.5	79	0.48	32	7	Labler-Packer
Siemens	0.75	73	0.44	58.7	6	Packer-Unloader
Siemens	0.75	73	0.4	53.3	6	Packer-Unloader
Siemens	0.75	73	0.4	53.3	6	Packer-Unloader
Siemens	0.75	73	0.42	56	6	Packer-Unloader
Siemens	0.75	73	0.38	50.7	6	Packer-Unloader
Siemens	0.75	73	0.36	48	8	Packer-Unloader
Siemens	0.75	73	0.41	54.7	8	Packer-Unloader
Sew	0.75	73	0.36	48	8	Packer-Unloader
Sew	0.75	73	0.36	48	8	Packer-Unloader

Type of Motors	Collected Data of Rated Power(kW)	Collected Data of Rated Eff.	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Sew	0.75	73	0.41	54.7	8	Packer-Unloader
Siemens	1.5	79	0.62	41.3	7	Washer
Siemens	4	73	2.81	70.3	6	Washer
Ksv	7.5	73	5.16	68.8	6	Washer
Ksv	4.5	77	2.8	62.2	6	Washer
Ksv	4	77	3.26	81.5	6	Washer
Ksv	4	77	2.75	68.8	6	Washer
Ksv	4	77	2.88	72	6	Washer
Ksv	4	77	2.9	72.5	6	Washer
Sew-Euro	0.75	77	0.4	53.3	6	Washer
Siemens	7.5	77	5.33	71.1	6	Washer
Siemens	7.5	77	5.39	71.9	6	Washer
Sew-Euro	0.75	73	0.41	54.7	6	Washer
Ssb	1	73	0.41	41	6	Washer
Ssb	1	73	0.4	40	6	Washer
Ssb	1	73	0.44	44	6	Washer
Ssb	1	73	0.38	38	8	Washer
Ssb	1	73	0.36	36	8	Washer
Ssb	1.6	73	0.56	35	8	Washer
Ssb	5.5	73	3.84	69.8	6	Washer
Ssb	11	73	6.7	60.9	6	Washer
Sew-Euro	2.2	73	1.2	54.5	6	Washer
Ksb	5.5	73	3.34	60.7	6	Washer
Ksb	5.5	73	3.44	62.5	6	Washer
Ksb	5.5	73	3.72	67.6	7	Filler
Ksb	1.5	73	0.5	33.3	7	Filler
Ksb	0.75	73	0.41	54.7	7	Filler
Ksb	6.4	73	5.4	84.4	7	Labler
Ksb	1.5	73	1.08	72	7	Labler
Ksb	3	73	2.52	84	7	Packer
Ksb	1.5	73	1.18	78.7	7	Packer
Ksb	1.5	73	1.15	76.7	7	Packer
Ksb	1.5	73	1.2	80	7	Packer
Ksb	0.75	73	0.54	72	7	Packer
Ksb	3	73	2.64	88	7	Unpacker

Type of Motors	Collected Data of Rated Power(kW)	Collected Data of Rated Eff.	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Ksb	1.5	73	0.54	36	8	Unpacker
Ksb	1.5	73	0.53	35.3	8	Unpacker
Ssb	37	73	32	86.5	6	Ammonia COMP
Ssb	90	73	68	75.6	6	Air Compressor
Grunfos	30	89	21.5	71.7	9	Bore Hole 1
Grunfos	15	89	11.3	75.3	8	Bore Hole 2
Grunfos	11	91	7.54	68.5	8	Water Trt,Degas
Grunfos	11	90	7.2	65.5	9	Water Trea,Settler Tank
Ssb	15	91	11.6	77.3	7	Water Treat,New,buffer
Ssb	1.5	73	0.9	60	7	Water Treat.,
Ssb	5.5	73	3.92	71.3	7	Water Treat.
Ssb	11	91	8.5	77.3	8	Water Treat. Filter
Ssb	5.5	73	4.08	74.2	7	Water Treat.
Ssb	4	73	2.5	62.5	8	Boiler,
Ssb	12	73	3.4	28.3	8	Boiler,
Ssb	3	73	1.2	40	8	Boiler,

5.3 Energy Performance Evaluation of Motors

In order to examine energy performance evaluation of motors, calculating or identification of power factor of motor, efficiency of motor and motor loading are very important parameters. In this section motor loading and efficiency are taken as motors performance evaluation parameters because there is a clear link between the motor's efficiency and the load. The Motors are designed to operate at 50%-100% load and to be most efficient at 75% load. High motor efficiencies and power factor close to 1 are desirable for an efficient operation and for keeping costs down of the entire plant [40].But the cutting value for low percentage loading depends on the rated power of motor.

As can be seen from figure 5.1 below;

i.For motors having rating of 0hp to 1.5hp, percent full load efficiency starts to drop rapidly below 50% motor loading.

ii. For motors having rating of 1.5hp to 5hp, percent full load efficiency starts to drop rapidly below 35% motor loading.

iii. For motors having rating of 10hp percent full load efficiency starts to drop rapidly below 30% motor loading.

iv. For motors having rating of 15hp to 25hp, percent full load efficiency starts to drop rapidly below 30% motor loading.

v.For motors having rating of 30hp to 60hp, percent full load efficiency starts to drop rapidly below 25% motor loading.

vi. For motors having rating of 75hp to 100hp, percent full load efficiency starts to drop rapidly below 20% motor loading.

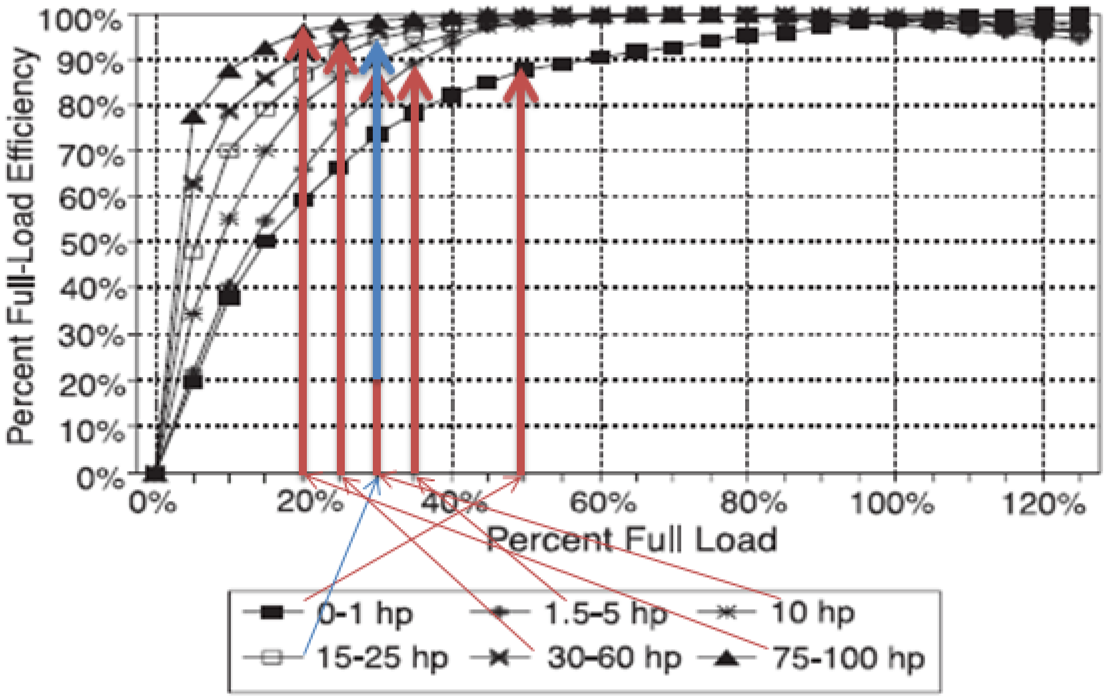

Figure 5.1:Chart of percent full load efficiency and percent full load of 0hp to 100hp motors[40]

As a result, it is useful to determine both the load and efficiency when assessing a motor's performance. However, when a motor has been in operation for a long period of time, it is often not possible to determine its efficiency because nameplates of motors are often lost or painted over. Hence motor loading can be used as performance evaluation for motors.

5.3.1 Motor Loading

The full load horsepower output rating of a motor is stamped on the motor's nameplate. A motor is a machine which drives load, and supply only that amount of power needed by the load. The load on the motor can be expressed as a percent of full load, and this is called the load factor for the motor.

Motor Load (%)= $P_{input}/P_{rated} = P_{output\ full\ load}/P_{rated}$ ……………………………………….…..….5.1

Whereas: P_{input}: The measured electrical input power to motor

$P_{output\ full\ load}$: Mechanical output power of the motor

P_{rated}:Rated power of the motor

The motor loading of each motor is tabulated in table 5.1 after being calculated using equation 5.1.From this table 5.1,motors of rating power of 0hp to 1.5hp, 10 motors have below 50%

motor loading; motors of rating 1.5hp to 5hp, 10 motors have below 35% motor loading; motors of rating 30hp to 60hp, 1 motor has below 25% motor loading. Other motors have loading percentage of above the cutting value. The motors installed in between loader to Unpacker, unpacker to bottle washer, bottle washer to filler, filler to labler, labler to packer, packer to unloader and in bottler washer are driving conveyors. Some of motors in washer are driving fans and holders of bottles. Motor connected to boiler is driving air blower. These low percentage loading motors have separate shafts to drive their corresponding loads. According to operators of the factory, except motors connected to boiler which operates 18hours per day(average),other motors connected on operation line run for 22hours per day and in average the factory runs for 24days per month throughout the year. Most of these motors are driving old conveyors which are old and repaired in some points. From the above discussions the reasons for low percentage loading of motors can be power mismatch (the amount of power needed by driven equipments is less than rated power of motors),the characteristics of driven equipment(old, repaired and not lubricated conveyors in the factory). Depending on this loading percentage cutting value of motors, 21 motors are identified from 105 motors audited from the factory.

5.3.2 General Comment of the Energy Performance of Electric Motors

As it can be seen from the table 5.1: out of 105 motors audited from the factory, depending on loading percentage cutting value of motors, 21 motors are identified having low value. As cited in [40] the optimum value of motor loading is ranging from 50%-100% load and to be most efficient at 75% load. From this it can be said that the factory is wasting energy. The important thing to be known here is that the low percentage loading of motors is not only due to motors' low efficiency but also due to power mismatch of motors to the load needed, characteristics of driven equipments and can be considered as an energy conservation opportunity.

Table 5 2 Motors having loading percentage of less than cutting value

Type of motors	Collected Data of Rated power(kW)	hp=Rated Power/0.746	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Sew-Euro Drive	0.75	1	0.28	37.3	13	Loader-Unpacker
Sew-Euro Drive	0.75	1	0.26	34.7	13	Loader-Unpacker
Siemens	1.5	2	0.47	31.3	9	Unpacker-Bottle Washer
Siemens	1.5	2	0.41	27.3	8	Washer-Filler
Siemens	1.5	2	0.36	24	8	Washer-Filler
Siemens	1.5	2	0.44	29.3	8	Washer-Filler
Siemens	1.5	2	0.48	32	13	Washer-Filler
Siemens	1.5	2	0.48	32	8	Washer-Filler
Siemens	1.5	2	0.5	33.3	8	Washer-Filler
Sew-Euro Drive	1.1	1.5	0.23	20.9	7	Filler-Labler
Siemens	1.5	2	0.48	32	7	Labler-Packer
Siemens	0.75	1	0.36	48	8	Packer-Unloader
Sew	0.75	1	0.36	48	8	Packer-Unloader
Sew	0.75	1	0.36	48	8	Packer-Unloader
Ssb	1	1.3	0.41	41	6	Washer
Ssb	1	1.3	0.4	40	6	Washer
Ssb	1	1.3	0.44	44	6	Washer
Ssb	1	1.3	0.38	38	8	Washer
Ssb	1	1.3	0.36	36	8	Washer
Ksb	1.5	2	0.5	33.3	7	Filler
Ssb	12	16	3.4	28.3	8	Boiler,

5.4 Energy Conservation Opportunities

The potential energy conservation opportunities identified for motors of the factory are: replacing low percentage motor loading, inefficient and old motors of the factory.

5.4.1 Technical Evaluation of Replacing the Existing Motors

As discussed in the table 5.1and table 5.2 there are motors with low percentage loading(less than cutting value), those with power rating greater than 0.75kW(motors of small power rating did not considered as they are insignificant) and those have served greater than 7 years(old motors) in the factory. Due to this the factory is wasting significant amount of energy. This energy loss can be minimized by replacing the motors with proper sized ones. Hence, replacing these motors is technically feasible. The table 5.3 below shows the motors to be replaced considering the aforementioned ideas.

Table 5 3 Technically feasible motors to be replaced.

Type of motors	Collected Data of Rated power(kW)	hp=Rated Power/0.746	Measured input Elec. power (kW)	Calculated Motor Loading (%)	Service year	Location of Motor
Siemens	1.5	2	0.47	31.3	9	Unpacker-Bottle Washer
Siemens	1.5	2	0.41	27.3	8	Washer-Filler
Siemens	1.5	2	0.36	24	8	Washer-Filler
Siemens	1.5	2	0.44	29.3	8	Washer-Filler
Siemens	1.5	2	0.48	32	13	Washer-Filler
Siemens	1.5	2	0.48	32	8	Washer-Filler
Siemens	1.5	2	0.5	33.3	8	Washer-Filler
Ssb	1	1.3	0.38	38	8	Washer
Ssb	1	1.3	0.36	36	8	Washer
Ssb	12	16	3.4	28.3	8	Boiler

5.4.2 Economical Evaluation of Replacing the Existing Motors

i)Energy Saving Analysis

The motors shown in table 5.3 need to be replaced by the new suggested ones as in table 5.4 below due to motors' low efficiency, due to power mismatch of motors to the load needed and characteristics of driven equipments and energy saved by replacing the existing motors is calculated as follow. But operating hours of motors connected to boiler and other motors connected to line of operation are different.

A motor connected to boiler operates for 18 hours and 24days per month (Electricians of the factory)

Annual Energy Consumed=Power (kW) x 12monthx24day/monthx18hr/day x0.5birr/kWh

A motor connected to other lines of operation operates for 22 hours and 24days per month (Electricians of the factory)

Annual Energy Consumed=Power (kW) x 12monthx24day/monthx22hr/day x0.5birr/kWh

Difference in cost of energy consumed= Energy consumed by existing motors- Energy consumed by replaced motors

(0.5ETB/kWh is flat multiplying factor from EEU)

Table 5 4 Energy saved from replacing motors

Type of motors	Existing motor, Rated power (kW)	Measured input Elec. power (kW)	Replacing Motor(Rated, kW)	Calculated Motor Loading (%)	Energy consumed by existing motors (ETB)	Energy cons. by new motors (ETB)	Difference (Saved energy in ETB)	Location of Motor
Siemens	1.5	0.47	0.5	31.3	4752	1584	3168	Unpacker-Bottle Washer
Siemens	1.5	0.41	0.5	27.3	4752	1584	3168	Washer-Filler
Siemens	1.5	0.36	0.5	24	4752	1584	3168	Washer-Filler

Siemens	1.5	0.44	0.5	29.3	4752	1584	3168	Washer-Filler
Siemens	1.5	0.48	0.5	32	4752	1584	3168	Washer-Filler
Siemens	1.5	0.48	0.5	32	4752	1584	3168	Washer-Filler
Siemens	1.5	0.5	0.5	33.3	4752	1584	3168	Washer-Filler
Ssb	1	0.38	0.5	38	3168	1584	1584	Washer
Ssb	1	0.36	0.5	36	3168	1584	1584	Washer
Ssb	12	3.4	4	28.3	31104	10368	20736	Boiler

ii)Cost Analysis

According to market survey, the cost of 0.5kW motor's price is about 3,600 Birr and 4kW motor's price is 6,000 Birr. Taking a salvage value of 1000birr for boiler connected motor and 500Birr for other motors (estimated by electricians of the factory) and by adding 40% (cost of purchasing with transportation, installation and other related costs) the following table is obtained.

Cost of new motor= (Price of motor+ 40% x Price of motor)Birr

Implementation Cost(Birr)=Cost of new motor – Salvage value

Table 5 5 Cost analysis of motors

Type of motors	Replacing Motor(Rated, kW)	Price of Replacing Motor	Cost of new motor(ETB)	Implementation cost(ETB)	Location of Motor
Siemens	0.5	3,600	5,040	4,540	Unpacker-Bottle Washer
Siemens	0.5	3,600	5,040	4,540	Washer- Filler
Siemens	0.5	3,600	5,040	4,540	Washer- Filler
Siemens	0.5	3,600	5,040	4,540	Washer-Filler
Siemens	0.5	3,600	5,040	4,540	Washer-Filler
Siemens	0.5	3,600	5,040	4,540	Washer-Filler
Siemens	0.5	3,600	5,040	4,540	Washer-Filler
Ssb	0.5	3,600	5,040	4,540	Washer
Ssb	0.5	3,600	5,040	4,540	Washer
Ssb	4	7,500	10,500	9,500	Boiler

iii)Payback Period

The payback period can be found by dividing the cost of replacing motors (annually) by the cost of energy saved from motors in a year.

Simple payback Period (SPP)= Implementation Cost(Birr)/ Annual energy cost saved

Table 5 6 Payback period of replaced motors

Type of motors	Replacing Motor(Rated, kW)	Implementation cost(ETB)	Difference(Saved energy in Birr)	SPP	Location of Motor
Siemens	0.5	4540	3168	1.4	Unpacker-Bottle Washer
Siemens	0.5	4540	3168	1.4	Washer- Filler
Siemens	0.5	4540	3168	1.4	Washer- Filler
Siemens	0.5	4540	3168	1.4	Washer-Filler
Siemens	0.5	4540	3168	1.4	Washer-Filler
Siemens	0.5	4540	3168	1.4	Washer-Filler
Siemens	0.5	4540	3168	1.4	Washer-Filler
Ssb	0.5	4540	1584	2.9	Washer
Ssb	0.5	4540	1584	2.9	Washer
Ssb	4	9,500	20736	0.5	Boiler

From the table 5.6 above the motors have payback period of 0.5 years, 1.4 years and 2.9 years. The approximate life time of the motors is 10 years and more so, replacing the existing motors is economically feasible energy conservation opportunity for the factory.

CHAPTER 6

ENERGY AUDIT OF WATER PUMPS IN THE FACTORY

6.1 Introduction

There are different water pumps with different specifications in the factory. The most critical aspect of energy efficiency in a pumping system is matching of pumps to piping system. Hence even if an efficient pump is selected, but if it is a mismatch to the system then the pump will operate at very poor efficiencies. In addition efficiency drop can also be expected over time due to deposits in the impellers and in the piping system. Given the significant amount of electricity attributed to pumping systems, even small improvements in pumping efficiency could yield very significant savings of electricity.

To investigate the energy performance of water pump and its motor, different data were collected using their nameplates, voltmeter, clamper, fluid flow meter, control board displays, meter, time watch, local control panel and by observation.

In this chapter energy usage performances of water pumps with their energy conservation opportunities and measures are discussed.

6.2 Water Pumps Inspection and Data Collection

In order to compute the energy performance of factory's water pumps, different data of water pumps were collected by inspection and measurement.

6.2.1 Data Collected by Measurement

In addition to visual inspection and interviews, data needed for the computation of water pumps energy performance analysis were collected using instruments like mechanical water flow meter, pressure gauge, clamper, local control panel, and control boards to measure volume flow rate ,Pressure(head), input power to motor, current and voltages.

The rated head data of the water pumps were collected from the data log and nameplates of the pumps themselves. To know the operating head data of the water pumps, the pressure gauges installed on pumps were used. In this, the level of pressure on suction and discharge side were read and their difference had been taken and converted to system international units (meter).

Pressure difference=Discharge side Pressure – Suction side pressure=ΔP

But: 1bar=10 meters(For water)

Table 6 1Pumps' Head Measurement

Pumps	Discharge side pressure(Bar)	Suction side Pressure(Bar)	Pressure Difference=ΔP	Head(m) =10xΔP
Degas pump	3	2.65	0.35	3.5
Water treat. (Settler)	3.5	2.7	0.8	8
Filter Pump	2.8	2.45	0.35	3.5
Buffer pump	3.5	2.3	1.2	`12
Blender pump	2.0	1.75	0.25	2.5

Since the submersible pump 1 and submersible pump 2 are installed in bore hole the estimated heads from the operators of the factory are used and they are 70m and 40m respectively. Only seven pumps were considered because of availability of pressure gauges on pumps and other data.

Table 6 2 Measured and nameplate data of water pumps

Discretions of Pumps	Nameplate data				Service Year	Measured data		
	ΔH,m	Q_{rated} (m^3/s)	Eff., η_{Motor}	Elec. Motor power, kW	Year	ΔH,m	Pm, $P_{elec.input}$ kW	Q(m^3/s)
Submersible pump 1	90	0.016	88.6	30	9	70	21.5	0.020
Submersible pump 2	70	0.016	88.6	15	8	40	11.3	0.021
Degas pump	30	0.01	91.2	11	8	3.5	7.54	0.025
Water treat. (Settler)	30	0.01	89.7	11	9	8	7.2	0.0143
Filter Pump	30	0.01	91.2	11	8	3.5	8.5	0.027
Buffer pump	40	0.016	91.2	15	7	`12	11.6	0.013
Blender pump	10	0.0008	73	3	2	2.5	1.7	0.0042

6.3 Motor Input Power, Pump Shaft Power, Hydraulic Power, and Pump Efficiency

6.3.1 Motor Input Power, Pm

The motor input power, Pm had been measured and tabulated in table 6.2.

6.3.2 Pump Shaft Power, P_s

The pump shaft power Ps is calculated by multiplying the motor input power by motor efficiency. To calculate the shaft power, it is better to use the efficiency of motor that to be read from figure 5.1 with corresponding motor loading percentage and motor loading. But the figure does not give clear value, hence rated efficiency of motor is used.

$Ps = P_m \times \eta_{Motor}$ ……………………………….……………………………………………6.2

6.3.3 Hydraulic power of Pump, Ph

Hydraulic power, Ph(kW) =Q (m^3/s) x h (m) x ρ (kg/m^3) x g ($9.81 m/s^2$)/1000……………..…..6.3

Where; ρ ($1000 kg/m^3$) - density of water

Flow(Q,m^3/s) Measurement Using Volume Time Ratio

In this method, using flow meter fitted on water lines, time is taken until the volume of water changes by $1m^3$.Then the ratio of volume to time taken will give volume flow rate(Q[m^3/s] of pumps. Q(m^3/s)=V/t [m^3/s]

6.3.4 Water Pump Efficiency(η_p)

$\text{Pump Efficiency} = (\text{Hyd. power, Ph(kW)})/(\text{Pump shaft power(kW)}) = Ph/Ps$………..…6.4

Table 6.3 Calculated parameters of pumps

Pump location	Operating parameters			Service Year	Ps	Ph	Eff. of Pump
	ΔH, m	Pm,kW	Q(m^3/s)	Year	(kW)	(kW)	%
Submersible pump 1	70	21.5	0.020	9	19.05	13.73	72
Submersible pump 2	40	11.3	0.021	8	10.01	8.24	82.3
Degas pump	3.5	7.54	0.025	8	6.87	0.86	12.5
Water treat.(Settler)	8	7.2	0.0143	9	6.45	1.12	17.4
Filter Pump	3.5	8.5	0.027	8	7.75	0.93	12
Buffer pump	`12	11.6	0.013	7	10.57	1.53	14.5
Blender pump	2.5	1.7	0.0042	2	1.24	1.03	83

6.3.3 Comment of the Energy Performance of factory's water Pumps

As calculated and tabulated in the table 6.3 above, the efficiency of the water pumps are: 72%, 82.3%, 12.5%, 17.4%,12%,14.5% and 83%.From this efficiency values 12%,12.5%,14.5% and 17.4% are very low values. The low efficiency values are may be due to different reasons such as mismatch between the efficient (good pump) and the piping system, inefficient pump (bad pump) and pump's motor sizing problem.

Pump Curves (Head – Flow curve), System Curve and Pump Operating Point

The pump performance curve of a pump shows the relationship of head and flow rate. In the pump as the head falls, the flow rate increases. System curve is basically a plot of system resistance(head to be overcome by the pump versus various flow rates).It changes with the physical configuration of the system such as elevation, diameter and length of piping. When a pump is installed in a system the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect.

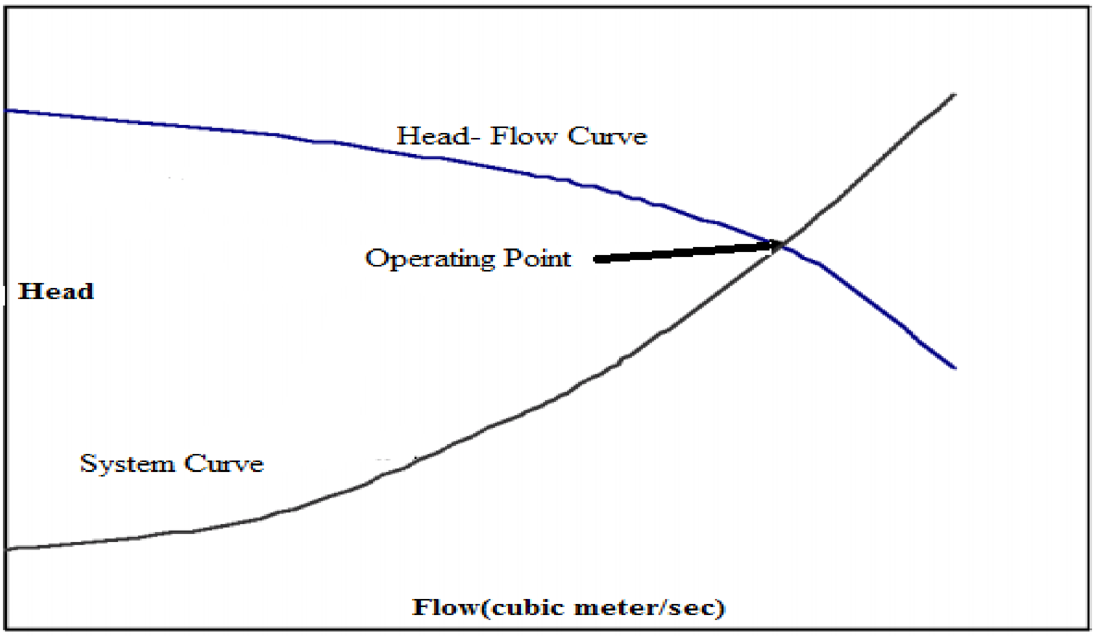

Figure 6. 1 Head- Flow Curve, System curve and Pump operating point

Pump efficiency varies with flow and head (pressure), and it is highest at one particular flow rate. The choice of pump for a given application depends largely on how the pump head-flow characteristics match the requirement of the system downstream of the pump.

For the water pumps considered in this section, the rated heads of Degas pump, Water treatment pump (Settler), Filter Pump and Buffer pump have high departure from the operating head(low heads).From figure 6.2,it can be said that as head falls the efficiency of pumps fall and deviates from best efficiency point(BEP). In addition to this the rated volume flow rate of these pumps is less than the operating values as given in table 6.3.From left to right as flow rate increases, the efficiency of pumps decrease(figure 6.2).Also the rated power of motors connected to pumps and the actual input power to motors have some difference.

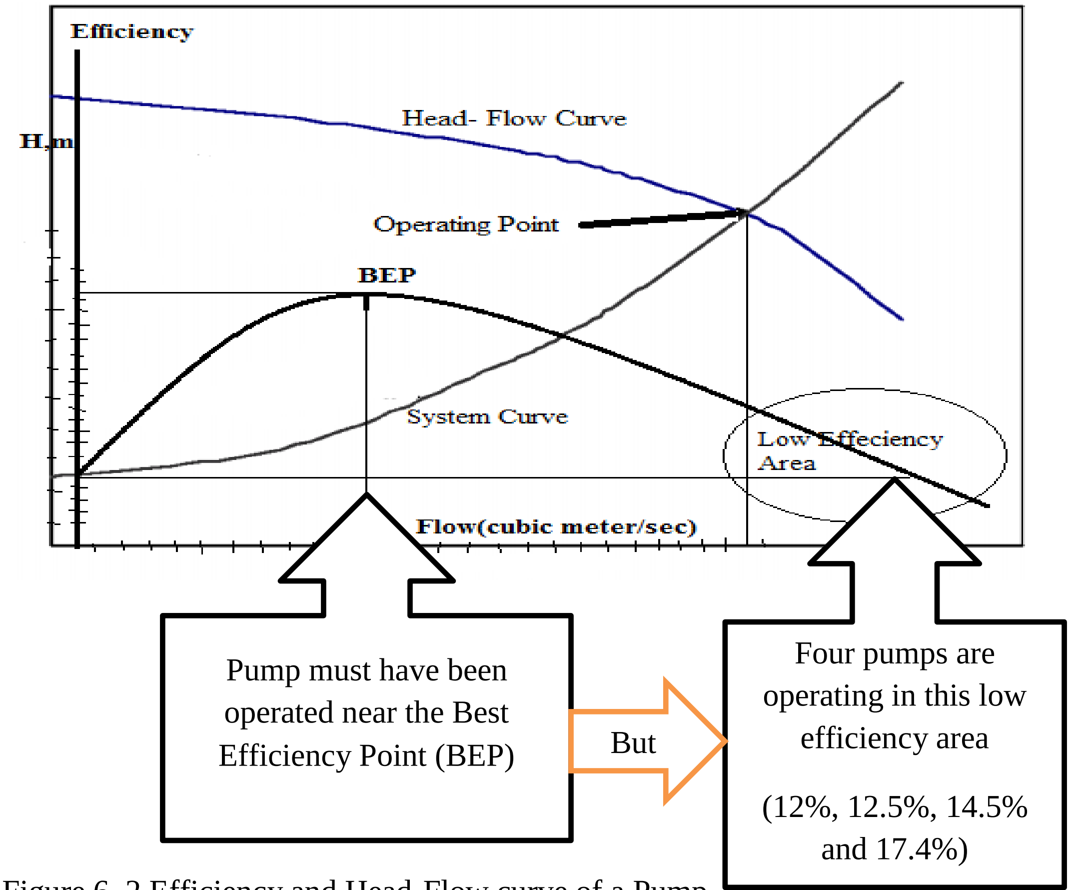

Figure 6. 2 Efficiency and Head-Flow curve of a Pump

Performance curve of the water pumps of the AMW factory could not found from the factory. As cited in [15],average water pump efficiency is 60%.But the four water pumps considered in this section(Degas pump, Water treatment-settler pump, Filter Pump and Buffer pump) are operating at very low efficiency(12%,12.5%,14.5% and 17.4%). From the discussions above it is not the reason why pumps are bad (inefficient) that resulted in low efficiencies, but the mismatch between the efficient (good pump) and the piping system and pump's motor sizing problem. This indicates that pumps are operating far away from the best efficient point (BEP).

6.4 Energy Conservation Opportunities

The audit analysis of the AMW factory's water pumps and their motors will end up with the following list of energy conservation opportunities.

1) Mismatch between the efficient (good pump) and the piping system
2) Housekeeping measures

6.4.1Technical Evaluation of Energy Conservation Opportunities

The energy audit conducted on the water pumps in the factory indicated that the energy conservation opportunities identified were mismatch between the efficient (good pump) and the piping system and housekeeping measures. The technical feasibility analysis of energy conservation opportunity number 2 like leakage of pump(filter pump) has no cost or low cost and can be handled by routine maintenance program. For energy conservation opportunity number 1 the technical analysis of improving pumps with low efficiency values is better for proper functioning of the factory by replacing the pumps that matches the required operational values.

6.4.2 Technical Evaluation of Replacing Pumps Operating With Low Efficiency

When a pump operate far away from best efficient point, it leads to high maintenance cost (seals, bearings) and energy wastage. This can be due to mismatch pump capacity with system requirement and it is better to replace with correct sized pump for efficient operation [15]. For this particular study the four pumps operating at low efficiency given in table 6.4 below are replaced with proper sized pumps.

Table 6 4 Rated and operating parameters of pumps operating with low efficiency

Pump location	Rated(Designed)Parameter			Operating Parameter(Measured)		
	Flow rate Q(m^3/hr)	Head(m)	Input Power, kW	Flow rate Q(m^3/hr)	Head(m)	Input Power, kW
Degas pump	36	30	11	90	3.5	7.54
Filter Pump	36	30	11	97	3.5	8.5
Buffer pump	60	40	15	47	12	11.6
Water treat. (Settler) Pump	36	30	11	52	8	7.2

Estimations of the Parameters of the Pumps to be Used

- In this, the heads are increased by 20% assuming that there are losses.
- Motor Efficiency is taken from the actual motor efficiency being used in the factory.
- Pump efficiency of 60% is used [15], which is an average pump efficiency.
- Input Power of the Motor are calculated with estimated parameters**.**

Input power of the motor= $P_{motor} = \rho_{water}$ xHx g x $Q/(\eta_{motor}$ x $\eta_{pump})$…………6.6

Table 6 5 Estimated Parameters

Pump and its location	Parameter to be used				
	Flow rate $Q(m^3/hr)$	Head,m	Pump Efficiency,%	Motor Eff.,%	Input Power of Motor(P_{motor}) kW
Degas Pump	90	4	60	91.2	1.8
Filter Pump	97.2	4	60	91.2	2.0
Buffer Pump	0.013	12.3	60	91	3.0
Water Treat.(Settler)	0.0143	8.2	60	90	2.0

Therefore, replacing these four pumps are technically feasible.

6.4.3 Economical Evaluation of Replacing Pumps Operating With Low Efficiency

In conducting economic analysis of replacing pumps operating with low efficiency, energy saved from difference in motor input power of pumps, cost of implementing the replacement of pumps and their respective simple payback are calculated.

i) Energy Saving Analysis

The energy saved was computed from the difference of motors' input power given to pumps. Annually Energy Saved= $[P_{motorOldPump} - P_{motorNewPump}]\times$Hours operated Annually

According to operators of the factory (Electricians), except motors connected to boiler which operates 18hours per day(average),other motors connected on operation line run about 22hours per day and in average the factory runs for 24days per month throughout the year.

Then; Hours operated Annually =12months x 24 days x 22 hours=6,336hrs

From table 6.5 and 6.6:

Annually Energy Saved (kWh)= $[P_{motorOldPump}-P_{motorNewPump}]\times 6{,}336$ or using electric energy flat rate of 0.78Birr/kWh (EEU);

Annually Energy Saved(ETB)= $[P_{motorOldPump}-P_{motorNewPump}]\times 6{,}336$ x0.78Birr/kWh

Table 6 6 Annual energy analysis of pumps

Pump and its location	Old Input Power of Motor ($P_{motor\ old}$) kW	New Input Power of Motor($P_{motor\ new}$) kW	Annually Energy Saved (ETB)
Degas Pump	7.54	1.8	28,368
Filter Pump	8.5	2.0	32,124
Buffer Pump	11.6	3.0	42,502
Water Treat.(Settler)Pump	7.2	2.0	25,700

ii) Implementation Cost of the Pumps

Cost of degas pump is estimated as 19500Birr and for filter pump 20500Birr,for buffer pump 25000Birr and Water Treatment(Settler)Pump 18000birr(factory operators Interview). Assuming 15% additional cost(transportation, installation and other costs) for each pumps and the total implementation cost is;

a) Implementation cost for degas pump=19500birr+ 0.15x19500 Birr=22,425.00Birr

b) Implementation cost for filter pump=20,500birr + 0.15x20,500 Birr=23,575.00Birr

c) Implementation cost for buffer pump=25000birr + 0.15x25000 Birr=28,750.00Birr

d) Implementation cost for Water Treat.(Settler)Pump=18000birr + 0.15x18000Birr=

20,700.00Birr

iii)Simple Payback Period (SPP)

SPP=Implementation cost/Cost of energy saved

Table 6 7 Simple Payback Period (SPP) of pumps

Pump and its location	Implementation cost (ETB)	Annually Energy Saved (ETB)	SPP Year	Rank
Degas Pump	22,425.00	28,368.00	0.79	3
Filter Pump	23,575.00	32,124.00	0.73	2
Buffer Pump	28,750.00	42,502.00	0.67	1
Water Treat.(Settler)Pump	20,700.00	25,700.00	0.8	4

6.5 Summary and Conclusion Remarks of Replacing Pumps Operating With Low Efficiency

In general, replacing the existing pumps operating with low efficiency is economically feasible energy conservation opportunity as the approximate service year of the pumps is much greater than recovery years and to improve its systems, the factory has to follow each and every points of operation and has to replace the water pumps with their rank of recovery period.

CHAPTER 7

ENERGY AUDIT OF AIR COMPRESSOR IN THE FACTORY

7.1 Introduction

Air compressor and its motor is another energy utilizing system in Ambo mineral Water factory. This factory uses a single-stage air cooled piston type reciprocating air compressor which has pressure vessel. The air compressor uses three-phase alternating current induction motor. It is used to operate pneumatic valves and other parts of the factory.

To investigate the energy performance of air compressor and its motor, data were collected using its nameplate, control board display, anemometer, meter, time watch, local control panel and observation. The results obtained from the detail audit of air compressor system indicated that its efficiency is 38.7% and the loading factor of the motor is 75.6%.Regular cleaning of compressor inlet ducts, filter and rearranging air distribution lines can reduce the losses so that the efficiency of the air compressor can be improved. In this chapter energy usage performances of air compressor with their energy conservation opportunities and measures are discussed.

7.2 Air Compressor and its Motor Data Collection

To investigate the energy performance of air compressor and its motor different data were collected using its nameplate, control board display, anemometer, time watch, local control panel and by observation.

7.2.1 Data collected for air compressor

Physical quantity measured/observed were maximum air inlet speed (on-load), minimum air inlet speed (off- load), on-load pressure, off-load pressure (outlet pressure), load time (t_{on}), off time (t_{off}),inlet temperature, pressure vessel volume, number of stage and inlet pressure and are tabulated as below.

Table 7.1 Collected air Compressor data

S/N	Physical Quantity measured/Observed	Value read/measured
1	On load pressure	7.3bar
2	Off load pressure(outlet Pressure)	8.3bar
3	Load time(t_{on})	36s
4	Off time(t_{off})	30s
5	Inlet temperature	27^0C
6	Pressure Vessel Volume	$0.9m^3$
7	Number of stage	Single
8	Inlet pressure	1.01bar

7.2.2 Data collected for air compressor's Prime mover (Motor)

Physical Quantities (parameters) measured/observed were power, motor loading factor, motor efficiency and power factor of the motor and tabulated as given below.

Table 7 2 Collected compressor's motor data

S/N	Physical Quantity(parameter) measured/Observed	Value obtained	
		Nameplate data	Operating data(measured/read)
1	Power	90kW	68kW
2	Motor efficiency	73%	73%
3	Power factor	0.81	0.80
4	Motor loading	75.6% (table 5.1)	

7.3 Determination of the Operating Efficiency of Air Compressor

To conduct operating efficiency of air compressor; mass flow rate of air, power gained by air and compressor's motor shaft (mechanical) power are computed and discussed.

7.3.1 Mass Flow Rate of Air

To calculate mass flow rate of air given to the air pressure tank volume(V);Inlet pressure(P1), outlet Pressure(P2), time taken to rise the outlet pressure (Trise), inlet air temperature(T) and universal gas constant (R_{air} =287) are used.

$\dot{m} = \frac{[(P2-P1)xV]}{[RairxTx\text{Trise}]} = \frac{[(830-101)x0.9]}{[287x304.95x36]}$=0.21kg/s(the air mass flow rate in ducts)……………….7.7

7.3.2 Power Gained by Air

The power gained by the air during it flows from inlet to out let is given as follow.

$P_{air\ gained}$=$\dot{m}$x[$(P_2/P_1)^{(k-1)/(kxN)}$ - 1]xCp…………………..……………………………………7.8

$P_{air\ gained}$ =0.21kg/sx[$(830/101)^{(k-1)/(kx1)}$ - 1]xCp, taking the specific heat ratio, k=1.4 [37].

$P_{air\ gained}$ =0.21kg/sx[$(830/101)^{(1.4-1)/(1.4x1)}$ - 1]x Cp=19.2kW

7.3.3 Air Compressor's Motor Shaft (Mechanical) Power

Compressor's Motor Shaft (Mechanical) Power is calculated by the product of electrical input power to the motor and rated motor efficiency(could not get actual efficiency). $P_{shaft\ of\ motor}$=$P_{electric\ input\ to\ motor}$ x η_{motor}=68kWx0.73=49.64kW,This is the amount of power that reaches at the shaft of compressor's motor.

7.3.4 Efficiency of the Air Compressor

The compressor's efficiency can be calculated by taking the ratio of Power gained by air to Compressor's Motor Shaft (Mechanical) Power($P_{shaft\ of\ motor}$) and given as follow.

$\eta_{Compressor}$= Power gained by air/ $P_{shaft\ of\ motor}$=19.2kW./56.94kW=38.7%.........................7.9

Table 7 3 The air compressor and its motor calculated parameters

S/N	Physical Quantity(Parameter) Calculated	Value obtained
1	Mass flow rate of air	0.21kg/s
2	Electric power input	68kW
3	Power gained by air	19.2kW
4	Compressor's Motor Shaft (Mechanical) Power($P_{shaft\ of\ motor}$)	49.64kW
5	Efficiency of the Air compressor	38.7%

7.4 Concluding remark of the Energy Performance of Air Compressor with its Motor

As tabulated in table 7.3, the efficiency of air compressor in the factory is 38.7 %. And the loading of the motor is 75.6%(table 7.2).But as cited in [33] the acceptable motor loading varies between 60% - 80%.In addition to this the power gained by the air for the reciprocating compressor deviates between 10 % - 40% of the electric energy input of the compressor's motor. The results obtained from the detail audit of air compressor system indicated that they are in the acceptable intervals.

7.5 Energy Conservation Opportunities

During the detail energy audit of the air compressor and is motor ECOs identified were: i) the compressed air distribution lines are far from the point of use.

ii) the air compressor inlet filter has absorbed dusts and rubbish.

7.5.1 Technical Evaluation of the ECOS Identified

Even if the motor loading and power gained by air compressor of the factory is within the recommended value, there are considerable energy saving opportunities for the air compressor of the factory. From the energy audit, the ECOs identified were the compressed air distribution lines are far from the point of use and the air compressor's inlet filter has absorbed dusts and rubbish. These ECOs can be done by staff of the factory with low costs or without costs through regular cleaning of compressor inlet ducts, filter and rearranging air distribution lines so that the distance between air compressor and points of use are minimized and the losses are reduced.

CHAPTER 8

DETAILED ENERGY AUDIT OF THE BOILER

8.1 Introduction

The factory uses fire-tube boiler with steam production capacity of 3,000 kg/h at 12bar and 191.7 ^{0}C. It uses diesel oil. It has been in service from 2009 to present. The boiler has feed water system, fuel system, air system and steam system. The boiler is used to develop steam which is directed through piping system to different points of use such as bottle washer. It produces steam at average temperature of 165^{0}C and 7bar. The boiler is cylindrical in shape and its three surfaces are exposed to the ambient air. The objective of this section is to evaluate the energy performance of the boiler in the factory.

In order to do this, different instruments such as combustion analyzer, mechanical flow meter, infrared thermometer, meter, verniers caliper and inspection has been used to collect data. From the data collected, the input and out mass of combustion system the boiler calculated were 27.22kg and 27.23kg respectively. The heat input, heat output and loss heat of the boiler calculated were 2,760kW, 2,122kW and 711kW respectively. The boiler's thermal and overall efficiencies were 74.2% and 72.2% respectively. The possible reasons identified for efficiency drop of the boiler were: Loss due to the presence of hydrogen in fuel ,loss due to dry flue gas, loss due to the moisture content of combustion air ,boiler shell loss, loss due to the moisture content of fuel, oversized boiler *etc.* and possible energy conservation opportunities identified from detail energy audit were: Repairing feed water treatment plant(cost of energy saved will be about 267,800Birr) and insulating boiler surface(cost of energy saved will be around 26,300Birr.)

In this chapter; data collection, determination of the actual operating efficiency of boiler, energy conservation opportunities, technical evaluation of ECOs, economical evaluation of ECOs and summary of energy conservation measures are discussed.

8.2 Boiler Inspection and Data Collection

In order to evaluate the energy performance of the boiler in the factory, different instruments such as combustion analyzer, mechanical flow meter, infrared thermometer, meter, verniers caliper and inspection has been used to collect data.

8.2.1 Data Collected by Visual Inspection and Interviews

To examine the energy performance of the boiler, data collected by visual inspection and interviews were: releases (blows down) time, service year of the boiler, material costs for boiler surface insulation, water treatment plant parts, operation time of boiler throughout the day, operation days of the factory and others.

8.2.2 Data Collected by Measurement

Data Collected by measurement are flue gas data, boiler surface data, blowdown temperature data, feed water temperature data, boiler dimensions data and volume flow rate data of fluids.

8.2.2.1 Flue Gas Data

To measure flue gas data, portable combustion analyzer was used. It removes a sample from the stack or flue with a vacuum pump and then analyzes the sample using electrochemical gas sensors.

Table 8.1 Flue Gas measured Data

S/N	Gas %/ ^{0}C /ppm measured	Value obtained
1	Ambient Temperature	25^{0}C
2	Flue gas temperature	198.7 ^{0}C
3	O_2 in flue gas	9.5 %
4	CO_2 in flue gas	8.5 %
5	Excess Air	83.3%
6	CO	7 ppm
7	Combustion Efficiency	83.3%
Free stream air composition Oxygen 21%, Nitrogen 79% Steam production at 165^{0}C and 7bar		

8.2.2.2 Boiler Surface, Blowdown and Feed Water Temperature Data

To estimate the energy lost from the boiler surfaces, surface temperatures of the boiler (cylindrical surface, the front and back surfaces), blowdown and feed water are measured by infrared thermometer.

Table 8.2 Boiler Surface, Blowdown and Feed Water Temperature and Ambient Temperature Data

S/N	Item	Temperature Measured	Ambient temperature
1	Boiler Cylindrical Surface	43^0C	27^0C
2	Boiler Front Surface	108^0C	30^0C
3	Boiler Back Surface	119^0C	28^0C
4	Feed Water Temperature	55^0C	
5	Blowdown Temperature	101^0C	
6	Ambient Temperature	25^0C	
Steam produced at a temperature 165 ^{0}C & pressure of 7 bar with Steam mass flow rate =0.768kg/s			

8.2.2.3 Boiler Dimensions Data

meter was used to measure the dimensions of the boiler (length, front diameter and back surfaces diameter).

Table 8 3 Boiler dimensions data

S/N	Boiler dimensions	Measured data
1	Length of boiler	3.68m
2	Diameter of front surface	1.61m
3	Diameter of back surface	1.61m

8.2.2.4 Volume Flow Rate of Fluids

Mechanical flow meters fixed on lines of fluid are used to measure the volume flow rate of fluids. It was done by waiting for 1 m^3 volume change on flow meter. Then volume flow rate of fluid was obtained by taking the ratio of 1 m^3 and time taken for 1 m^3 change on flow meter of fluid(t).

Table 8.4 Volume flow rate of Fluids

S/N	Fluid	Volume flow rate[m^3/s]
1	feed water to boiler	0.0008
2	feed fuel oil to boiler	$7x10^{-5}$
3	Blowdown	$2\ x10^{-4}$
4	Steam mass flow rate =0.768kg/s	

8.2.3 Check for Mass Balance of the Data Collected

To compute the boiler input and output heat energy, the mass balance of combustion system and steam system must be determined first.

8.2.3.1 Mass Balance of the Combustion System

1) Mass Flow Rate of Fuel Oil

To calculate the chemical energy of the fuel, mass flow rate of the fuel has to be known and is given by;

Mass flow rate of fuel= $\dot{V}_{Fuel\ oil}$x Density of fuel oil……………………………………8.1

- Density of feed oil=848kg/m^3
- Using table 8.4: Volume flow rate of Fluids

$\dot{m}_{fuel} = 7x\frac{10^{-5}m^3}{s}x848\text{kg/m3}$ =0.0594kg/s

2)Mass Balance of Fuel Oil Combustion

In order to calculate the amount of energy liberated during furnace oil combustion, the mass of fuel oil, the combustion air and the combustion products are very important.

a)Air Fuel Ratio of Fuel oil Combustion

The actual mass of air supplied/ kg of fuel (AAS),theoretical air fuel ratio and excess air of fuel oil are computed so that the mass flow rate of flue gases can be obtained.

Actual mass of air supplied/ kg of fuel (AAS) = {1 + Excess Air/100} x theoretical air

But, Theoretical Air =[(11.6 x C) +{34.8 x(H_2 - O_2 /8)}+(4.35 x S)]/100 kg of air /kg of oil. To calculate the theoretical air, composition of diesel oil and ultimate analysis (%) given in the table 8.5 below are used.

Table 8.5 Composition of Diesel oil and Ultimate Analysis (%)

Composition of Diesel oil	Ultimate Analysis in (%)
Carbon (C)	85
Hydrogen (H_2)	13
Oxygen (O_2)	0.75
Sulphur(S)	0.25
Nitrogen (N_2)	0.5
Moisture M	0.5

Table 8.6 Molecular weight of the constituents of the fuel oil

Element or Compound	C	O_2	H_2	S	N_2	CO_2	SO_2	HO_2
Molecular Weight	12	32	2	32	28	44	64	18

Theoretical Air =[(11.6 x C) +{34.8 x(H_2 - O_2 /8)}+(4.35 x S)]/100 kg of air/kg of oil……………………………………………………………………………………8.2

TA=(11.6 x0.85) +{34.8 x(0.13 – 0.0075 /8)}+(4.35 x 0.0025) =14.36kg of air/kg of oil

Excess air supplied (EA) =$(O\%)/(21\% - O2\%)x100$……………………………………8.3

To calculate the excess air, flue gas data measured by Combustion Analyzer(it removes a sample from the flue with a vacuum pump and then analyzes the sample using electrochemical gas sensors.)given in the table 8.1 is used.

Excess air supplied (EA) =$(9.5\%)/(21\% - 9.5\%)x100$=82.6%

For oil fired boiler the recommended percent of excess air is 15% with the volume percent of CO_2 15% [38] while the calculated average excess air supplied to the furnace of the AMW factory's boiler is 82.6% (83.3% from flue gas analyzer) with the volume percent of CO_2 being 8.5%.This high excess air affects energy loss due to dry flue gas. From this discussion, the volume percent of $C0_2$ is in required range and the excess air can be controlled by reducing motor capacity of air blower of the boiler.

Then; Actual mass of air supplied/ kg of fuel (AAS) = [1 + Excess Air/100] x theoretical air

AAS=[1 + 82.6/100] x 14.36=26.22kg of air/kg of oil……………………………………8.4

b)Mass of Dry Flue Gases

The mass flow rate of the flue gases must be calculated to have energy losses due to flue gases. To do this the molecular weight of the constituents of the fuel and composition of fuel oil and their ultimate analysis are crucial for the actual chemical reaction(the combustible elements in furnace oil are carbon, hydrogen and sulphur) in the boiler.

1kg of fuel + Dry air → CO_2 + H_2O+ SO_2 + N_2 ,…………………………..…………..8.5

when a kg of fuel is completely burnt by dry, carbon dioxide, water vapor and sulphur dioxide, with inert nitrogen are produced as shown in the above reaction.

i)Mass of Carbon dioxide(kg) per 1kg of fuel

$C + O_2 \rightarrow CO_2$

12 + 32 → 44 ; From this equation ,12 kg of C requires 32 kg of O_2 to form 44 kg of CO_2 therefore 1 kg of C requires (32/12 kg=2.67 kg) of O_2. Then by taking ultimate analysis of C percentage in diesel oil(Table 8.5 :85%)

$0.85xC + 0.85x2.67O_2 \rightarrow 3.12CO_2$

ii) Mass of Sulphur dioxide (kg) per 1kg of Diesel Oil

$S + O_2 + \rightarrow SO_2$

32 + 32 → 64

From the above reaction 32 kg of S requires 32 kg of O_2 to form 64 kg of SO_2, therefore 1 kg of S requires (32/32 kg = 1 kg)of oxygen. Then by taking ultimate analysis of S percentage in diesel oil(Table 8.5:0.25%)

$0.0025S + 0.0025x1O_2 \rightarrow 0.005SO_2$

iii)Mass of Water(kg) per 1kg of Diesel Oil

$2H_2 + O_2 \rightarrow 2H_2O$

4 kg + 32kg → 36kg

From the above reaction 4 kg of hydrogen requires 32 kg of Oxygen to form 36 kg of water vapor (H_2O), therefore 1 kg of H_2 requires 8 kg of O_2. Then by taking ultimate analysis of H_2 percentage in diesel oil(Table 8.5:13%)

$0.13H_2 + 0.13x8O_2 \rightarrow 1.17H_2O$, Here mass of water=$m_{v,H2\ O}$ =1.17kg of water vapor/1kg of diesel oil.

$\dot{m}_{flue\ gas}$: Mass flow rate of dry flue gas.

m= mass of CO_2 + mass of SO_2 + mass of N_2 + mass of O2

m= $(0.85x44)/12 + (0.0025x64)/32 + (AASx77)/100 + EAx\frac{23}{100}$

But, EA=AAS-TA=26.22-14.36=11.86 kg of air per kg of fuel

m=$(0.85x44)/12 + (0.0025x64)/32 + (26.22x77)/100 + 11.86x\frac{23}{100}$=26.035 kg of flue gas per kg of fuel

But, mass flow rate of dry flue gas=$\dot{m}_{flue\ gas}$ =m x mass flow rate of diesel oil=mx$\dot{m}_{fuel}$

=26.035 kg of flue gas / kg of fuel x0.0594kg fuel /s

$\dot{m}_{flue\ gas}$=1.5kg of flue gas/s…………………………………………………………………8.6

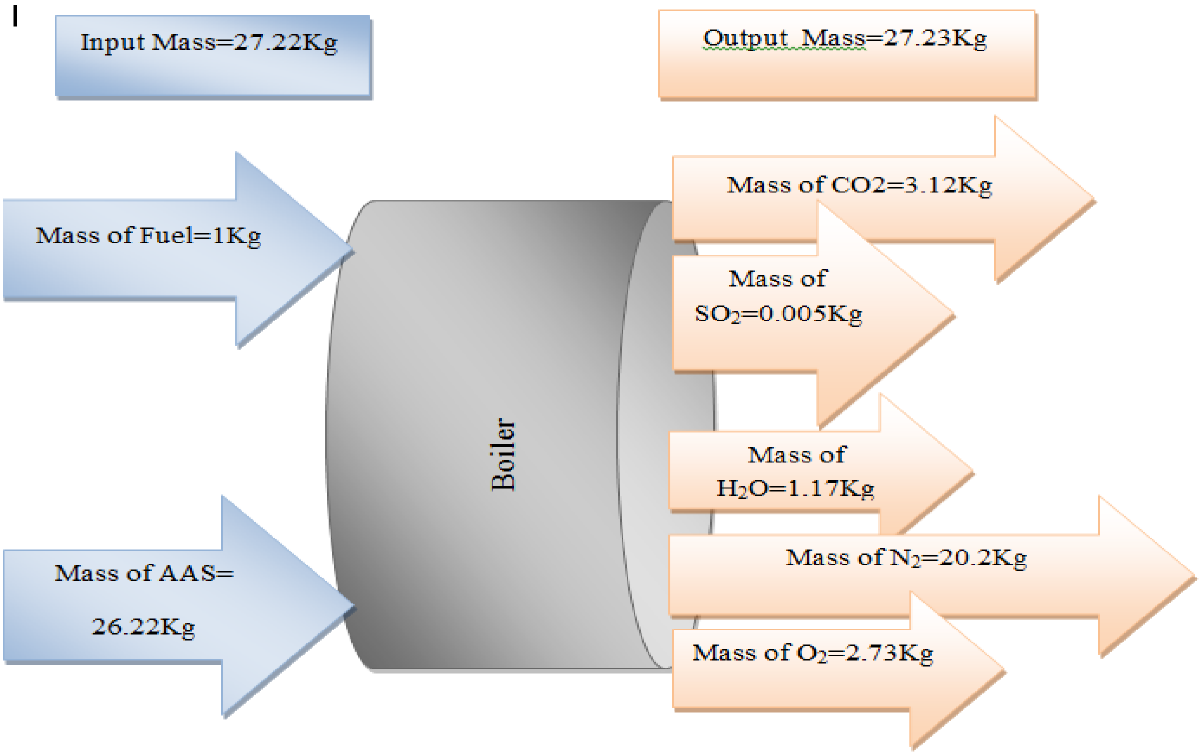

Figure 8. 1 Combustion system mass balance of Boiler

8.2.3.2 Concluding Remark of the Mass Balance of Combustion System

As it was shown the figure 8.1, total input mass (mass of fuel and actual air supplied) given to the boiler is 27.22kg while the output mass(Mass of CO_2, Mass of SO_2, Mass of H_2O, Mass of N2 and Mass of O_2)is 27.23kg with the difference of 0.01kg,which is insignificant discrepancy (may due to round off error).Therefore, the collected combustion system data is reliable.

8.2.3.3 Mass Balance of Steam System

1) Mass Flow Rate of Feed Water

Mass flow rate of feed water is important to calculate input energy of feed water(the enthalpy of water obtained by increasing the ambient temperature to feed water temperature) and it is given by:

Mass flow rate of feed water=$\dot{m}_w$= $V_{flow\ rate\ water}$x Density of feed water…………………8.7

$\dot{m}_w$= $(0.0008m\text{^}3)/s$x 985kg/m^3 =0.788kg/s ,(Table 8.4: Volume flow rate of Fluids and Density of feed water=985kg/m^3 at 55^{0}C)

2) Mass Flow Rate of Blowdown

Mass flow rate of blowdown is essential to compute energy loss due to blowdown. The factory operates with 3 shifts per day. The factory releases (blows down) once per shift for about 10 minutes (interviewing and observation in the factory)

i.e Total time blowdown per day=

3shiftsx1 blowdown/shiftx10min/blowdown=30minutes=1,800seconds

Since there is no flow meter,, by using timer and 5liters gercon during blowdown, it took 9 seconds to fill 5liters of a gercon. From this:

$$\dot{V}_{blowdown} = \frac{5L}{9s} = \frac{0.005m^3}{9s} = 5.6x\frac{10^{-4}m^3}{s}$$

And From the blowdown temperature (table 8.2, 101^0C)

Mass flow rate of water blow down= $\dot{V}_{blowdown}$x Density of water at 101^0C……………..8.8

From steam table,ρ_{water}=1/specific volume at 101^0C=$\frac{1}{0.0010435}\frac{\text{kg}}{\text{m3}}$ =958.3kg/m^3

$\dot{m}_{blowdown}\ at\ blowdown\ time = 5.6x\frac{10^{-4}m^3}{s}x958.3\text{kg/m3}$ =0.54kg/s (this is only for blowdown time).But the boiler operates for 18 hours per day(Boiler room operator)

Then for throughout the day;

$$\dot{m}_{blowdown} = \frac{0.54\frac{\text{kg}}{s}}{18\text{hr x}3600\frac{\text{s}}{\text{hr}}}\text{ x }1800\text{s} = 0.02\frac{\text{kg}}{\text{s}}$$

1) Mass Flow Rate of Steam

Mass Flow Rate of Steam is used to calculate energy output of the boiler. Mass flow rate of steam can be obtained as follow.

For the particular boiler in the factory the feed water is input mass (water) while blow down and steam are the output masses.

Mass of Feed Water input=Mass of water blow down + Mass of Steam

Mass of Steam= Mass of Feed Water input - Mass of water blow down

Mass flow rate of steam= Mass flow rate of feed water- Mass flow rate of blow down

$$\dot{m}_{steam} = \dot{m}_{feed\ water} - \dot{m}_{blowdown} = 0.788\frac{kg}{s} - 0.02\frac{kg}{s} = 0.768kg/s \ldots\ldots\ldots 8.9$$

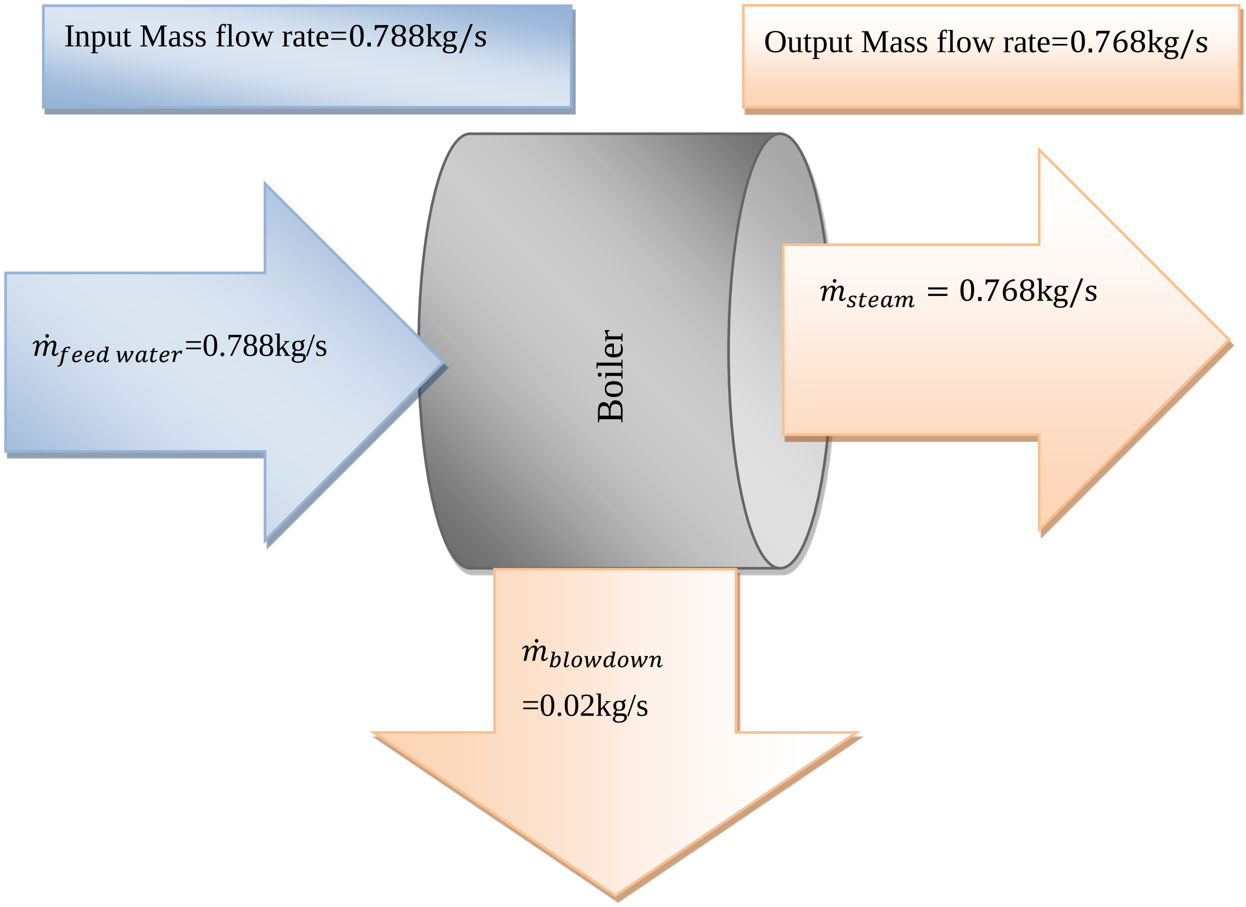

Figure 8. 2 Steam system mass balance of Boiler

8.2.3.4 Concluding Remark of the Mass Balance of Steam System

As it was shown the figure 8.2, the feed water given to the boiler is 0.788kg/s, while the output steam mass flow rate is 0.788kg/s (sum of blowdown and steam).In this leakage is assumed to be negligible. Therefore, the collected steam system data is reliable.

8.3 Determination of the Actual Operating Efficiency of Boiler

To calculate actual operating efficiency of boiler one can use: **i) Direct Method (input-output method):-** The absorbed energy of the working fluid, water and steam is compared with the energy of fuel given to the boiler. The efficiency of boilers can be calculated easily as it requires few parameters for computation, but does not give any clue (does not calculate various losses) as to why efficiency of the boiler decreased. As a result indirect method is used in this paper**.**

ii) Indirect Method (Thermal and Combustion Efficiency Method): The efficiency of the boiler can be calculated by subtracting the heat losses (does not include blowdown) from input heat. In this method, to determine of the actual operating efficiency of the boiler, the input energy (energy due to feed water, diesel oil and combustion air) and the output energy of the boiler (the energy of steam and energy losses: dry flue gases loss, heat loss due to hydrogen in oil, heat loss due to moisture content of combustion air, heat loss due to radiation and convection from the boiler surface and heat loss due to moisture content of the fuel) need to be computed.

8.3.1 Energy Inputs to the Boiler

The input energy such as feed water, diesel oil and combustion air of the boiler are calculated as follow.

8.3.1.1 Energy of Feed Water Supply

Input energy of feed water supply is the enthalpy of water obtained by increasing the ambient(25C^0) temperature to the feed water temperature(55C^0) and it is given by:

Input Energy due to feed water(Q_W)=Mass flow rate of feed water ($\dot{m}_w$) x Specific heat of water(C_W)x(Feed water temperature(T_W) - Ambient temp(T_a))

$Q_W = \dot{m}_w x C_w x (T_w - T_a)$…………………………………………………………..….8.10

Mass flow rate of feed water=0.788kg/s(from equation 8.7)

But C_w =4.18KJ/kg^{0}C

Then: $Q_{feed\ water} = \dot{m}_{feed\ water} x C_{water} x \left(T_{feed\ water} - T_a\right)$

=(0.788kg/s)x(4.18KJ/kg^{0}C)x(55^{0}C-25^{0}C)=(0.788kg/s)x(4.18KJ/kg^{0}C)x(30^{0}C)

=98.8kW

8.3.1.2 Energy of Diesel Oil Supply(Chemical Energy)

The input energy due to diesel oil contains chemical energy due to its chemical constituents and internal heat energy (taken as zero when measured relative to ambient temperature condition, no pre-heating of the fuel at inlet to boiler).

To calculate the chemical energy of the fuel (diesel oil), quantification of its heating value used and is given by:

Chemical energy of the fuel= Mass flow rate of the fuel x Gross calorific value of the fuel

Q $_{\text{Diesel oil chemical Energy}}$ =$\dot{m}_{diesel\ oil} x\ GCV_{diesel\ oil}$……………………………………….8.11

But the mass flow rate of diesel oil can be determined by:

$\dot{m}_{fuel}$ =0.0594kg/s(from equation 8.1)

Then: Q $_{\text{oil chem Enegy}}$ =$\dot{m}\ _{fuel} x\ GCV_{fuel}$=(0.0594kg/s)x44,800KJ/kg=2,661.12kW

8.3.1.3 Energy of Combustion Air

As there is no air preheating, the inlet temperature of air is nearly the same as ambient temperature. Hence, the relative enthalpy of combustion air is zero. (It is taken to be zero when measured relative to the ambient condition not because of it does not contain internal energy)

8.3.1.4 Auxiliary Electrical Energy Inputs

Auxiliary electrical energy inputs to the boiler are electrical energy such as input energy to motor of blower. As compared to fuel and water supply energy to the boiler it is negligible, hence assumed to be zero.

8.3.2. Energy Output of the Boiler

When feed water entered to the boiler is converted to steam, the produced steam carry away huge amount of output energy (heat) and can be calculated as follow.

$Q_{Heat\ of\ Steam}$ =Mass Flow Rate of Steam x Enthalpy of super-heated steam at a temperature of 165^{0}C and pressure 7 bar.

$Q_{Heat\ of\ Steam} = \dot{m}_{steam\ produced\ per\ second} x h_{gs}$ ……………………………………..8.12

But, Mass flow rate of steam =$\dot{m}_{steam}$ = 0.768kg/s(from equation 8.9)

$$Q_{Heat\ of\ Steam} = 0.768\text{kg}/s x h_{gs}$$

h_g =Enthalpy of super-heated steam at a temperature of 165^{0}C and pressure 7bar is 2763.5KJ/kg

$Q_{Heat\ of\ Steam} = \dot{m}_{steam\ produced\ per\ second} x h_g$=0.768kg/s x2763.5KJ/kg=2,122.4kW

8.3.3 Energy Losses of the Boiler

The energy losses of the boiler are dry flue gases loss, heat loss due to hydrogen in fuel oil, heat loss due to moisture content of combustion air, heat loss due to radiation and convection from the boiler surface and heat loss due to moisture content of the fuel.

8.3.3.1 Heat Loss Due to Dry Flue Gas

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

heat loss due to dry flue gas=Q_{flue}=$\dot{m}_{dry\ flue\ gas}x\ C_p\ [T_{flue} - T_a]$……………………….8.13

But, mass flow rate of dry flue gass=$\dot{m}_{flue\ gas}$ =1.5kg of flue gas/s(from equation 8.9)

Q_{flue}=$\dot{m}_{dry\ flue\ gas}x\ C_p\ [T_{flue} - Ta]$= $\dot{m}_{flue\ gas}$xC_p x(T_{flue}-25^{0}C)=1.5x1.88x(198.7-25)=489.8kW

8.3.3.2 Heat Loss due to the Presence of H_2 in Fuel

It is known that water contains Hydrogen and Oxygen. During combustion process of the fuel oil the hydrogen in it reacts with oxygen and water will be formed. The water formed takes away some of the energy liberated during the combustion process and this energy loss is as below.

$Q_{hydrogen\ in\ fuel}$ = m_{H2O} x[latent heat of vapor at 25^{0}C + Specific heat capacity($T_{flue\ gas}$ -Ta)] $x\dot{m}_{fuel}$ ……………………………………………..…………………………...8.14

From section 8.2.3.1 i) mass of water=m_{H2O} =1.17kg of water/1kg of diesel oil.

ii)Mass flow rate of diesel oil= $\dot{m}_{fuel}$=0.0594kg/s (from equation 8.1)

iii)Enthalpy of water at 25^{0}C=h_{fg}=2441.12KJ/kg

iv) Cp =Specific heat capacity=1.88KJ/kg=0.45kCal/kg

v)Temperature of flue gas=$T_{flue\ gas}$=198.7^{0}C(table 8.1)

vi)Ambient temperature=Ta=25^{0}C(table 8.1)

$Q_{hydrogen\ in\ fuel}$ = m_{H2O} x[latent heat of vapor + Specific heat capacity($T_{flue\ gas}$ -Ta)] $x\dot{m}_{fuel}$

=1.17kg[2441.12KJ/kg +1.88KJ/kg ^{0}C x(198.7^{0}C -25^{0}C)] 0.0594kg/s=192kW

8.3.3.3 Heat Loss due to Moisture Content of Fuel

Most of fuels have moisture and during combustion process of these fuels water is going to be formed, as a result it takes away some of the energy liberated during the combustion process. This energy loss due to moisture in the fuel is given by:

$Q_{moisture\ in\ fuel}$ = Moisture in fuel [Latent heat of vapor + Specific heat capacity($T_{flue\ gas}$ - Ta)] $x\dot{m}_{fuel}$ ……………………………………..…………………………………………...8.15

Moisture in fuel=0.5(table8.5) and fuel mass flow rate(equation 8.2)

Cp=0.45kcal/kg=1.88kJ/kg

$Q_{moisture\ in\ fuel}$=(0.5/100)[2441.12+1.88(198.7-25)]x0.0594=0.8kW

8.3.3.4 Heat Loss due to Moisture Content of Combustion Air

The combustion air under standard condition contains moisture and the energy loss due to moisture content of the air is s given as follow.

$Q_{loss,moistureof\ comp.Air}$=Actual Air supplied x $\dot{m}_{fuel}$ x Humidity of combustion air xCp (T_{flue} - Ta)………………………………………………………………………………………8.16

From section,8.3.3.2, AAS =26.22kg of air/kg of oil and Mass flow rate of fuel=0.05kg/s

The average relative humidity of the air used for combustion is φ = 53.25% [31] and humidity factor (γ A) =0.01211 kg of H2O/ kg of dry air.[35]

And Specific heat of superheated steam=Cp=1.88KJ/kg. K=0.45kCal/kg

Then; $Q_{loss,moistureof\ comp.Air}$=Actual Air supplied x $\dot{m}_{fuel}$ x Humidity of combustion air xCp (T_{flue} - Ta)=26.22x0.059kg/s(198.7-25)x1.88x0.01211=6kW

8.3.3.5 Heat loss due to Radiation and Convection from the Boiler Surface

i)Radiation energy loss: due to difference in temperature between the ambient air and the boiler surface.

ii)Convention energy loss: energy lost from the boiler surface to the surrounding wind by convection.

$Q_{surface} =$

$$\left[0.548\left(\left[[\frac{Ts}{56.55}]^4\right]-\left[[\frac{Ta}{56.55}]^4\right]\right)+1.957\left[[Ts-Ta]^{1.25}\sqrt{\frac{196.85Vwind+68.9}{68.9}}\right]\right]\frac{w}{m2}xS_{area}\ldots\ldots 8.17$$

$$Q_{surface} = Q_{front} + Q_{back} + Q_{cylindrical}$$

Where Ts=Surface temperature: T_{front} =108^{0}C =381.15^{0}K , T_{back} = 119^{0}C=392.15^{0}K and $T_{cylindrical}$=43^{0}C=300.15^{0}K

Ta:Ambient temperature(local): $T_{front\ local\ ambient}$ =30^{0}C=303.15^{0}K ,$T_{back\ local\ ambient}$ =28^{0}C =301.15^{0}K and $T_{cylindrical\ local\ ambient}$=27^{0}C=300.15^{0}K

V=Wind velocity taken to be taken 2.56 m/s

But: $r_{front\ area} = r_{back\ area}$=0.805m and $l_{cylinderical} = 3.68m$

- Front area of boiler=$A = S_{front\ area} = \pi r^2 = \pi 0.805^2 = 2.0358m^2$
- Back area of boiler=$A = S_{back\ area} = \pi r^2 = \pi 0.805^2 = 2.0358m^2$
- Cylindrical area of boiler=$S_{cylindrical\ area} = \pi DL = \pi x 1.61 x 3.68m^2$
  $= 18.6133m^2$

Q_{Front} =2036.54xS_{front}=4.145kW

$Q_{Cylinderical}$ =288.21xS_{cyl} =5.364kW

Q_{Back} =2471.97S_{back}=5.032kW

$Q_{\mathbf{Boiler\ Surface}} = Q_{Front} + Q_{Cylinderical} + Q_{Back}$ =4.145kW +5.364kW +5.032kW=14.5kW

8.3.3.6 Heat Loss Due to Blowdown Water from the Boiler

Dissolved solids contained in the water remain in the boiler when water is boiled and steam is generated. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. The deposits also lead to scale formation inside the boiler, resulting in localized overheating and finally causing boiler tube failure. Hence blow down is significant for these removing of deposits, however can be source of heat loss, if improperly carried out and given by:

Energy loss due to boiler blowdown= Mass flow rate of blowdown x Enthalpy of blowdown at 101^{0}C and 1.046 bar…………………………………………………………………………...8.18

But, $\dot{m}_{blowdown}$ =0.02kg/s(from equation 8.8)

Energy loss due to boiler blowdown= Mass flow rate of blowdown x Enthalpy of blowdown at 101^{0}C and 1.046 bar

$Q_{blowdown}$=0.02kg/sx419.04KJ/kg=8kW

In order to analyze the input energy to the boiler and the output energy from the boiler with the assumption, energy can neither be created nor destroyed, the energy balance calculated is summarized as below.

Table 8.7 Energy Balance Analysis of the Boiler

<table>
<tr><th>S/N</th><th>Input Energy to Boiler(kW)</th><th>Heat Loss(kW)</th><th>Output Heat, kW</th><th>Heat, kW</th></tr>
<tr><td>1</td><td>Energy of Feed Water=98.8</td><td>Heat Loss Due to Dry Flue Gas =489.8</td><td rowspan="8">Useful steam heat to process =2,122</td><td rowspan="8">$\sum_1^6 Losses$+ Q_{Steam} =2,833</td></tr>
<tr><td>2</td><td>Input Energy of fuel=2,661.12</td><td>Heat Loss due to the Presence of H2 in Fuel =192</td></tr>
<tr><td>3</td><td>Energy of Combustion Air=0</td><td>Heat Loss due to Moist. of Comb. Air=6</td></tr>
<tr><td>4</td><td>Electrical Input=0</td><td>Heat Loss due to Moisture Content of fuel=0.8</td></tr>
<tr><td>5</td><td rowspan="2">$\sum_1^4 Input\ Enegy$==2,760</td><td>Heat Loss Due to Blowdown Water from the Boiler=8</td></tr>
<tr><td>6</td><td>Heat by Radiation and Convection from the Boiler Surface=14.5</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td>$\sum_1^4 Losses$=688.6</td></tr>
<tr><td>$\sum_1^6 Losses$=711</td></tr>
</table>

In order to represent the losses in percentage the following calculation is necessary.

i. Percentage heat loss due to dry flue gas = [m_{flue} x Cp(T_f – T_a)/GCV of fuel]x 100

m = mass of dry flue gas in kg/kg of fuel

Cp – Specific heat of superheated steam (0.45 kcal/kg =1.88kJ/kg)

=[26.22x1.88x(198.7-25)/44800]100=19%

ii. Percentage heat loss due to H2 in fuel=[[9x H_2 (584 + Cp(T_f – T_a))]/GCV of fuel]x 100

Where, H2 – kg of H2 in 1 kg of fuel

Cp – Specific heat of superheated steam (0.45 kcal/kg =1.88kJ/kg)

584 is the latent heat corresponding to the partial pressure of water vapor

=[[9x 0.13 (584 + 1.88(197.8 – 25))]/44800]x 100=2.4%

iii. Percentage heat loss due to moisture present in fuel

= [[M (584 + Cp(T_f – T_a)]/GCV of fuel]x 100

Where, M – kg of moisture in 1kg of fuel

=[0.005(584 + 1.88(197.8 – 25))]/44800]x 100=0.01%

iv. Percentage heat loss due to moisture present in air=[[AAS x humidity factor Cp(T_f – T_a)]/GCV of fuel]x 100

=[26.22 x 0.01211 x 1.88(197.8 – 25))]/44800]x 100=0.23%

v. Radiation, convection and blowdown losses are approximated to be 2%.

8.4 Energy Sankey Diagram (Energy Balance) of the Boiler

The following Sankey diagram is used to represent an entire input, output and losses(percentage)energy calculated of the boiler.

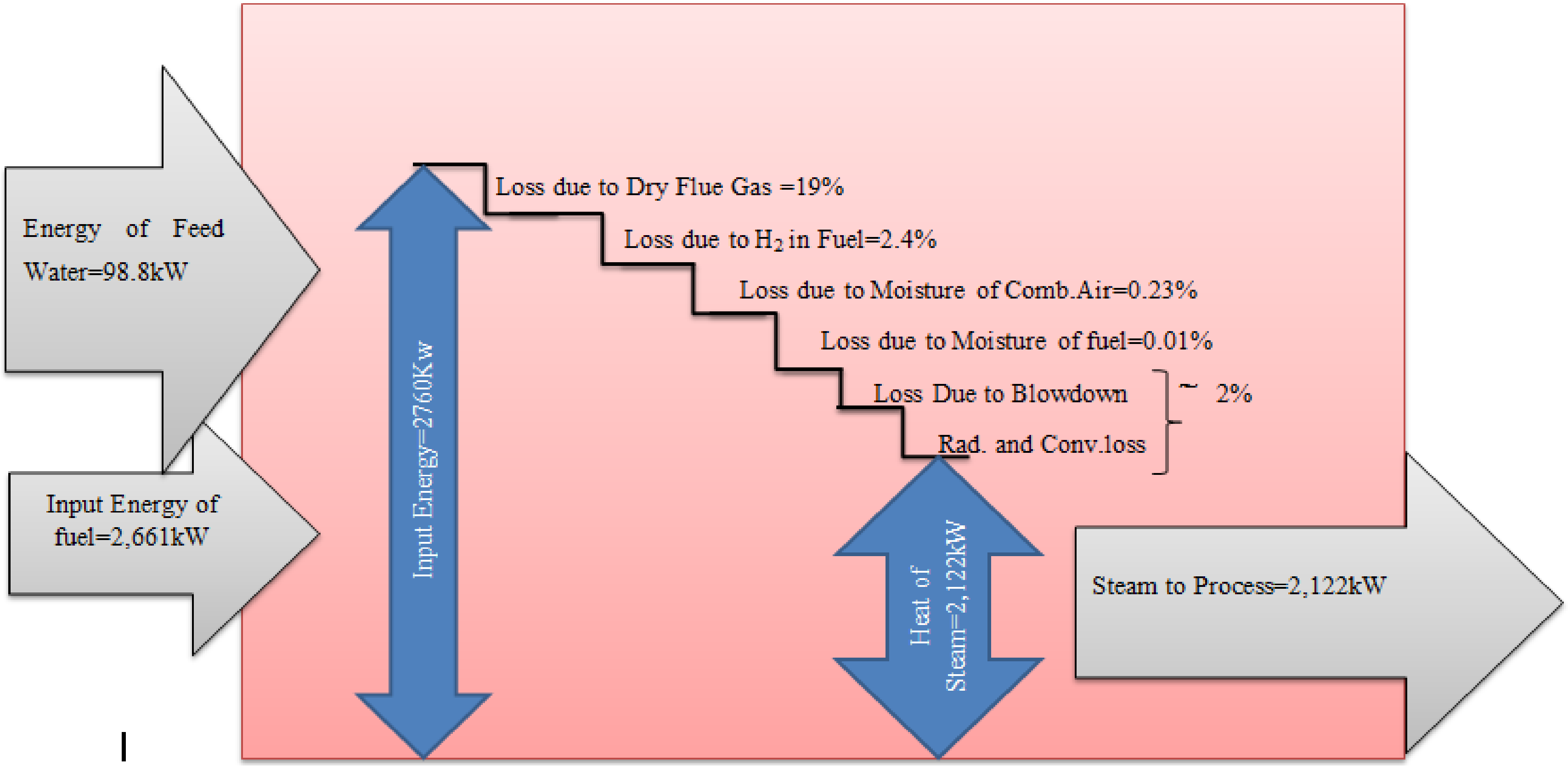

Figure 8. 3 Energy Sankey diagram and losses in percentages

8.5 Concluding Remark of the Heat Balance of the Boiler

As it is tabulated in the table 8.7, the average total input heat given to the boiler is 2,760kW while the output and losses are 2,833kW with the difference of 0.025% which is acceptable. This difference may be due to the problem of water treatment plant which results in boiler shell losses and which can be taken as energy conservation opportunities.

8.6 Actual Operating Efficiency of the Boiler

The efficiency of the boiler is used to define the performance of the boiler. It indicates the percentage with which heat input is effectively utilized to generate steam. In this section indirect method of boiler efficiency calculation is used.

a) Combustion Chamber Efficiency

It is given by:

Combustion chamber Efficiency= $\mathbf{1-\frac{[\sum_1^4 \textit{Energy Losses}]}{\textit{Total Energy Inputs}}}$……………………………..….8.19

By substituting the energy inputs and losses in table 8.7,

Combustion chamber Efficiency =1-688.6/2760=75%

b)Thermal Efficiency of the Boiler

It is given by:

Thermal Efficiency $=1-\frac{[\sum_1^6 Energy\ Losses]}{Total\ Energy\ Inputs}$

By substituting the energy inputs and losses in table 8.7,

Thermal Efficiency $=\eta_{\text{thermal efficiency}}$=1-711/2760=74.2%...8.20

c) Overall Boiler Efficiency

To compute the overall efficiency of the factory's boiler the energy losses, energy input to the boiler and boiler shell loss are used.

$$\eta_{\text{total boiler efficiency}}=\left[1-\frac{[(\sum_1^6 \text{Energy Losses})+\text{Boiler Shell Loss}]}{\text{Total Energy Inputs}}\right]*100\%$$

Boiler shell loss is significantly appeared in the boiler because from the detail energy audit of boiler the input and output side heat are not balanced. Consequently, the heat delivered to the fluid (feed water) and the heats produced within the boiler's furnace have non negligible departure. Hence, boiler shell loss is calculated as below.

$Q_{b.shell\ loss}$= ηthermal efficiencyx$[[\sum_1^6 \text{Energy Losses} + \text{Qsteam}] - [\sum_1^4 \text{Energy Input}]]$

$Q_{b.shell\ loss}$ =74.2%(2,833,-2,760)=54.2kW…………………………………..…..…….8.21

Then ,by including boiler shell loss, the boiler overall efficiency is given as follow.

$\eta_{total\ boiler\ efficiency}$= $\left[1 - \frac{[711+54.2]}{2760}\right] * 100\% = 72.2\%$...8.22

8.7 Concluding Remark on Efficiency of Boiler

From the combustion chamber efficiency of the boiler it is 75%. The boiler's thermal efficiency is 74.2% and the overall boiler efficiency is 72.2%.Even if it is less than the recommended design performance of furnace oil fired boiler (85%) [35]the boiler's efficiency of the factory is in good condition.

The possible reasons for efficiency drop of the boiler are:

- Loss due to dry flue gas =19% (energy conservation opportunities).
- Loss due to the presence of H_2 in fuel=2.4% (unavoidable losses)
- Loss due to the moisture content of combustion air=0.23% (unavoidable losses).
- Loss due to the moisture content of fuel=0.01% (unavoidable losses).
- Boiler shell loss (energy conservation opportunities)
- Loss of heat by radiation and convection from boiler surface (energy conservation opportunities)
- Oversized boiler(energy conservation opportunities)

8.8 Energy Conservations opportunities (ECOs)

Among the ECOs identified above loss due to the presence of hydrogen in fuel, loss due to the moisture content of fuel and loss due to the moisture content of combustion air are unavoidable losses While loss due to dry flue gas, boiler shell loss, loss of heat by radiation and convection from boiler surface are energy conservation opportunities. The amount of hardness contamination that comes from improper water treatment plant can result in scale deposits on tubes of boiler and this intern causes the reduced heat transfer to feed water. From factory's operators (Boiler operator) interview, the factory is not conducting regular cleaning for boiler's tube and some parts of the tubes of the boiler have scale deposit. Therefore, the following listed ECOs technical and economical evaluation is discussed in detail.

a) Repairing boiler feed water treatment plant

b) Insulated boiler surface

c) Installing an economizer

d) Replacing oversized boiler

8.8.1 Technical Evaluation of the Energy Conservation Opportunities

From detail energy audit of the boiler, it was revealed that there are considerable energy savings potential in the boiler of the factory such as repairing water treatment plant, boiler surface insulation; replacing the existing boiler with proper size and installing an economizer are discussed.

8.8.1.1 Technical Evaluation of Repairing Water Treatment Plant

The amount of hardness contamination that comes from improper water treatment plant can result in scale deposits on tubes of boiler and this intern causes the reduced heat transfer to feed water, hence boiler shell loss. Then boiler shell loss brings decreased efficiency of boiler. As calculated in previous, the shell energy loss is 54.2 kW. This loss can be reduced by repairing water treatment plant of the factory. The factory has enough space and human skill for replacing water treatment plant and it is technically feasible.

8.8.1.2 Technical Evaluation of Replacing the Existing Boiler

The boiler of factory was designed to produce 3 ton/hr at 191.7^0C and 12bar and from energy audit of boiler conducted, steam consumed by factory is 2.12ton/hr at 165^0C and 7bar .Due to this oversizing, there is loss of energy and can be reduced by replacing the existing boiler of the factory. But the boiler in the factory has been working for only 10 years while it can work for more than 25 years (operator interview).Hence, replacing it is technically not feasible.

8.8.1.3Technical Evaluation of Boiler Surface Insulation

The boiler of the factory is cylindrical in shape and it has length of 3.68m and diameter of 1.61m for both front and back surfaces (measured by meter).

Figure 8. 4 Boiler surface of the factory

Three surfaces of boiler exposed to the ambient air with their respective average temperature are: front surface temperature of 108^0C(381.15^0K),back surface temperature of 119^0C(392.15^0K) and cylindrical surface temperature of 43^0C(300.15^0K). Front area of $2.0358m^2$ (4.145kW loss), back area of $2.0358m^2$(5.032kW loss) and cylindrical area of $18.6133m^2$(5.364kW loss) having total boiler surface loss of 14.5kW.To avoid this lose, insulating boiler surface is taken as one of ECOs and it is technically feasible.

8.8.1.4 Technical Evaluation of Installing Economizer

Installation of economizer in a given factory is used for preheating the feed water which offers an increase in overall thermal efficiency of the boiler by reducing the flue gas exit temperature. **F**or the furnace oil fired boiler, the flue gas exit temperature from a boiler is usually maintained at approximately 200^0C [38]. The Ambo Mineral Water factory has no an economizer. Its average flue gas temperature is 198.7^0C which is in accepted range. As a result installing an economizer for the factory is not feasible.

8.8.2 Economic Evaluation of the Opportunities

In this section energy saving analysis, implementation cost and simple payback period of repairing water treatment plant and insulating boiler surface are discussed.

8.8.2.1 Economic Evaluation of Repairing Water Treatment Plant

In order to conduct economic evaluation of repairing water treatment plant energy saved from thermal and overall efficiency, gross calorific value of fuel and mass flow rate of fuel are used. Also implementation costs and simple payback period are conducted here.

i) Energy Saving:-Assuming electrical energy to the air blower motor of the boiler is negligible when compared to fuel energy to the boiler and the energy of fuel that can be saved by repairing the water treatment plant is 54.2kW(equation 8.19).The total amount of cost of energy saved by repairing the water treatment plant is about 267,800Birr or 12,750liters of fuel oil.

ii) Implementation Cost: For cleaning equipments (fire tube, about 132,000 birr), filtering materials (10,000birr), and chemicals and for other expenses (15,000Birr), the roughly estimated cost for repairing water treatment plant is 157,000birr.(Factory's Operators interview)

iii) Payback Period: The simple payback period can be computed by taking the ratio of the cost of implementing the repairing water treatment plant to cost of energy saved.

Simple Payback period (SPP)=Implementation cost/cost of energy saved

SPP=157,000birr/267,800Birr=0.586Year

Since the simple payback period is about 7 month, the repairing of water treatment plant is economically feasible.

8.8.2.2 Economic Evaluation of Replacing the Existing Boiler

To conduct economic evaluation of replacing the existing boiler; cost energy saved, implementation cost and simple payback period are calculated.

i) Energy Analysis

Energy Saved from replacing boiler =steam mass flow rate difference x hg at 165^0C and 7bar

Assuming 15% (as the time varies the steam demand varies) steam is needed in addition to currently produced,

Energy Saved = (Steam production design value - Steam consumed) x hg at 191.7^0C and 12bar

Energy Saved=(3-(0.15x2.12+2.12))1000/hr x 2788.3KJ/Kg=435kW

From this energy saved, the cost of energy saved through the year is about 2,000,000birr which save about 100,000 liters of fuel oil.

ii) Implementation Cost: For boiler having specifications of 2.4ton/hr which produces steam at 165^0C and 7bar, the rough estimate of boiler price is 8,000,000birr.(Factory's Operators interview) and the assumed salvage value for the existing boiler is to be 1000,000 Birr.(Factory's Operators interview). The installation cost, transportation cost and other costs of the boiler to be replaced are estimated to be increased with 40%(Factory's Operators interview).Then;

Implementation cost= [(8,000,000 birr -1,000,000 Birr)+ 0.40x8,000,000birr]

=10,200,000birr

The financial loss due to interruption of production to implement energy conservation opportunities/measures is assumed to be negligible.

iii) Payback Period: The simple payback period can be computed by taking the ratio of implementation cost to cost of energy saved annually.

Simple payback period (SPP)= implementation cost/Cost of energy saved

SPP=10,200,000birr/2,000,000birr= 5.1 years, this is long time to recover the investment cost of a single equipment. Hence, replacing the existing boiler is not economically feasible.

8.8.2.3 Economic Evaluation of Boiler Surface Insulation

i) Saving Analysis

As mentioned in technical analysis boiler has surface loss of 14.5kW.Assuming that the factory will accomplish the task of insulation by recovering surface loss of 70%(operator interview),10.15kW energy will be saved or about 26,300 birr(0.5birr/kWh taken ,EEU) which saves about 1,250 liters of fuel oil.

ii)Implementation Cost

The surface insulation of the boiler consists :Cost insulating materials for total area of boiler($2.0358\text{m}^2 + 2.0358\text{m}^2 + 18.6133\text{m}^2$ =22.68m^2) with 40mm thickness of insulation is assumed to be 14,500birr (boiler operator interview) and other miscellaneous costs of 5,500 birr(total of 20,000birr).

iii)Payback Period

The simple payback period can be computed by taking the ratio of implementation cost to cost of energy saved annually.

Simple payback period (SPP)= implementation cost/Cost of energy saved

SPP=20,000birr /26,300birr=0.76Year

From this it takes only 9 months to recover the investment costs and insulating boiler surface is economically feasible for the factory.

8.9 Summary-List of Energy Conservation Measures

Table 8.8 Summary-List of Energy Conservation Measures

S/N	Energy Saving Measure	Annual Saving (ETB)	Implementation cost (ETB)	Simple Payback Period(Year)	Rank
1	Repairing Water Treatment Plant	267,800	157,000	0.586	1
2	Boiler Surface Insulation	26,300	20,000	0.76	2

8.10 Conclusion Remarks

From the overall energy audit of the boiler, in order to increase the efficiency of the boiler, to increase profitability and to create conducive working condition to the factory, Ambo Mineral Water factory has to apply energy saving measures ranked on annual saving as repairing water treatment plant and insulating surface of the boiler.

CHAPTER 9

ENERGY AUDIT OF STEAM DISTRIBUTION SYSTEM

9.1 Introduction

Steam distribution systems consist of piping lines and the steam traps from a boiler to points of use, condensate return lines, and other equipments like pumps needed for condensate return. The wearing and deterioration of these equipments may cause energy wastage. Energy management can affect this system by improving the insulation, detecting and repairing steam and condensate leaks, maintaining the steam traps and condensate pumps, and providing water treatment. The steam distribution system should be inspected at the same time the boiler is inspected and energy can be saved by insulating the pipes that carry either steam or condensate. In order to conduct the energy performance evaluation of steam distribution lines data were collected by using portable instruments like infrared thermometer, meter (length) and by inspection. From the energy audit conducted, by insulating steam lines energy saved from insulation is around 15,150Birr annually with simple payback period of 0.26 year and the energy costs saved from steam leakages is around 56,500Birr with simple payback period of 1.13 year. For this particular factory the condensate that comes from point of use (bottle washer) is taken back to the boiler feed water tank and increases the temperature of feed water to 55^{0}C. Some steam trap points in Ambo Mineral Water Factory has problems, as there is small condensate in steam, which affect the dryness of steam(points on heat exchanger around bottle washer) and need considerations in order to maximize operating efficiency of steam strap and as a whole. In this chapter, energy performance evaluations of steam distribution lines are discussed with their respective energy conservation opportunities and measures.

9.2 Data Collection

9.2.1 Steam Line Surfaces' Data Collected

In order to conduct the energy performance evaluation of steam line surfaces data were collected by using portable instruments like infrared thermometer, meter(length) and by inspection.

Table 9 1 Steam line surface measured data

S/N	Physical quantity measured	Value obtained
1	Ambient Temperature	25^0C
2	Insulated surface Temperature	70^0C
3	uninsulated surface Temperature	105^0C
4	Length of bare line	6m
5	Length of insulated line	6m
6	Diameter of insulated line	0.17m
	Diameter of uninsulated line	0.17m

9.2.2 Steam Leakage Data Collected

To examine the proper functioning of steam lines with steam transportation data were collected by using portable instruments like infrared thermometer, meter(length) and by inspection.

Table 9 2 Steam leakage measured data

S/N	Physical quantity measured	Value obtained
1	Number of leakage holes	5
	Leaking holes diameter	1mm
2	Leakage Temperature	121.1^0C

9.3 Energy Performance Evaluation of Steam Pipeline Surfaces

The objective of the steam pipeline is to supply steam at the correct pressure and temperature to the point of use. But uninsulated steam pipelines can cause significant heat energy loss as it is exposed to the surrounding. Hence, insulation is needed to avoid the loss of heat through radiation from steam pipes.

9.3.1 Heat Loss from Insulated and Un-Insulated Steam Line Surfaces

In Ambo Mineral Water Factory the steam pipeline that is lined to bottle washer has uninsulated part with the data given in table 9.1 above. The heat loss from it can be calculated using the following equations:

Hot surface (Insulated surface) temperature=Th=70^0C

Ambient Temperature=Ta= 25^0C

Surface area of insulated pipeline=$A = \pi\text{DL} = \pi\text{x}0.17\text{mx}6\text{m} = 3.2m^2$

Where L is length=6m and D is diameter=0.17m of the insulated pipe respectively.

Surface heat loss=Sloss=[10+(Th-Ta)/20](Th-Ta)……………………………………………9.1

=[10+(70-25)/20](70-25)=551.25 kCal/hr m^2

Total heat loss[kCal/hr]=$H_{loss\ 1}$=SxA…………………………...………………………9.2

=551.25 kCal/hr m^2 x3.2m^2=1,766.44 kCal/hr

Factors like wind velocity, and conductivity of insulating material have been neglected.

Hot surface (uninsulated surface) temperature=Th=105^0C

Ambient Temperature=Ta= 25^0C

Surface area of uninsulated pipeline=$A = \pi\text{DL} = \pi\text{x}0.17\text{mx}6\text{m} = 3.2m^2$

Where L is length=6m and D is diameter=0.17m of the uninsulated pipe respectively.

Surface heat loss=S[m^2]=[10+(Th-Ta)/20](Th-Ta)=[10+(105-25)/20](105-25)

=1,120 kCal/hr m^2

Total heat loss[kCal/hr]=$H_{loss\ 2}$=SxA=1,120 kCal/hr m^2 x3.2m^2=3,584 kCal/hr

Total reduction in heat loss Hs = Hloss2 –Hloss1…………………………….………………9.3

=3,584 kCal/hr-1,766.44 kCal/hr=1,817.56kCal/hr

$$Equivalent\ Fuel\ Loss(Hloss)\left(\frac{kg}{year}\right) = \frac{\text{Hloss x yearly hours of operation}}{\text{GCVof fuel}(\frac{\text{kCal}}{\text{kg}})\text{ x ŋboiler}} \quad \text{……………………..…9.4}$$

Gross calorific value of fuel oil = 10,800 kCal/kg

$$Equivalent\ Fuel\ Loss(Hloss)\left(\frac{Kg}{year}\right) = \frac{1{,}817.56\frac{\text{kCal}}{\text{hr}}\text{ x 6240hr}}{10{,}800(\frac{\text{kCal}}{\text{kg}})\text{ x ŋboiler}}$$

=(1,817.56 kCal/hr x 6240hr)/(10,800(kCal/kg) x 0.833)=1,260.68kg/year,

9.3.2 Energy Conservation Opportunities

From energy investigation of the factory's steam distribution lines energy conservation opportunities identified are:

- Some parts of steam distribution lines are not insulated.
- Regular inspection of steam lines need to be conducted

9.3.3 Technical Evaluation of Energy Conservation Opportunities

Among energy conservation opportunities identified, regular inspecting of steam lines can be done by staff of the factory without incurring any cost but with high importance. On the other hand, even if insulating steam lines need significant amount of costs; since it can reduce losses and bring efficiency it is technically feasible.

9.3.4 Economical Evaluation of Energy Conservation Opportunity(Insulating Steam Lines)

In this section energy analysis, costs of materials and labor needed to implement the measures and computation of simple payback period are discussed. Assuming fuel oil cost = 12ETB/kg

Annual costs of heat loss (Birr) = Hloss x Fuel cost (Birr/kg)………..……………………….9.5

=1,260.68kg/yearx12ETB/kg=15,128.16Birr/year

ii) Implementation Cost

In order to insulate the steam lines ,medium temperature insulator(include 85 percent magnesia, asbestos, calcium silicate and mineral fibers having temperature range of 90 – 325^{o}C), is going to be constructed. From the previous experience in the factory, the cost of insulating steam line per meter with 40mm thick is about 650birr.

Hence, the total average insulating cost will be:6mx650birr/m=3,900birr

iii) Simple Payback Period

The simple payback period can be estimated as follow.

Simple Pay Back Period=Implementation Cost for insulation/Energy Saved from insulation

Simple Pay Back Period =3,900birr/15,128.16Birr/Year=0.26 Year.(i.e it takes about 3 months to have return needed.)

9.4 Steam Leakages in the Factory

Steam leaks can be expensive if large amounts of steam are lost and are a source of energy loss and must be avoided. In the Ambo Mineral Water Factory five points each having average hole diameters of 1mm(0.0394inch)have been identified which are leaking steam at average temperature of 121.1^{0}C(250^{0}F) that goes to bottle washer.

9.4.1 Heat Losses Due to Steam Leakages

The pounds of steam lost can calculated with a formula Grashof's formula [36] gives the number of pounds of steam lost per hour through an orifice of area A as:

Steam Loss(lb/h) =0.70 x0.0165x3600 xA x$P^{1.97}$

Where,

0.70 = coefficient of discharge for hole (for a perfectly round hole, this coefficient is 1)

0.0165 = a constant in Grashof's formula

3600 = number of seconds per hour

A = area of hole in square inches

$A = \pi r^2 = \pi r^2 = \pi 0.0197^2 = 0.00123 inch\ square$

P1 = pressure inside steam line in psia

From the steam table[36,p6], Enthalpy, Btu/lb hg= 1164 Btu/lb, P=29.825 psia

Then; Steam Loss(lb/h)=0.70 x0.0165x3600 xA x$P^{1.97}$

Steam Loss(lb/h)=0.70 x0.0165x3600 x0.00123 x$29.825^{1.97}$ =40.97lb/h

But; Heat loss(Btu)= Steam Loss(lb/h)x(Btu/lb)x(operating hours/year)

Heat loss(Btu)=40.97x1164x12x24x18Btu=247,220,190.7Btu/Year

But, 1Btu=0.2931wh,Then Energy lost through the year from steam leak is 72,460.2kWh

9.4.2 Energy Conservation Opportunities

- Some parts of steam distribution lines are old and need replacement
- Some parts of steam distribution lines are not insulated.
- Each node and valve points of distribution lines need to be fitted properly
- Regular inspection of steam lines need to be conducted

9.4.3 Technical Evaluation of Energy Conservation Opportunity

From energy conservation opportunities identified, fitting nodal points properly and regular inspecting of steam lines can be done by staff of the factory without incurring any cost. Conducting regular basis maintenances, insulating steam lines and replacing them can contribute to reduction of energy losses from steam leakages and increment of efficiency of the parts. Hence, it is technically feasible.

9.4.4 Economic Evaluation of Energy Conservation Opportunity

i) Energy saving analysis

The energy costs of the steam leaks can be estimated by the following equation

Heat loss, energy lost through the year from steam leak is 72,460.2kWh

Cost/year = Heat loss x electric energy bill flat rate

Taking 0.78ETB/kWh(bill flat rate from EEU,2018);

Cost/year=72,460.2kWhx1.5ETB/kWh=56,519Birr,this is the amount of energy cost will be saved if properly managed.

ii) Implementation Costs

To implement the insulation of lines/nodal points, replacement of some parts of lines/parts and other activities related to them, it is roughly estimated to cost about 64,000 birr.(Interview)

iii) Simple Payback Period (SPP)

SPP=Implementation Cost/Cost of Energy Saved=64,000 birr /56,519birr=1.13 year

9.5 Condensate Recovery of the Factory

Steam turns to water containing only sensible heat after giving up its latent heat to heat the process. An efficient steam system collects condensate and either return it to a boiler feed tank, or use it in another process. Only when there is a real risk of contamination should condensate not be returned to the boiler. Condensate is discharged from steam plant and equipment through steam traps from a higher to a lower pressure. Unless reused the release of condensate to the environment can cause loss of energy.

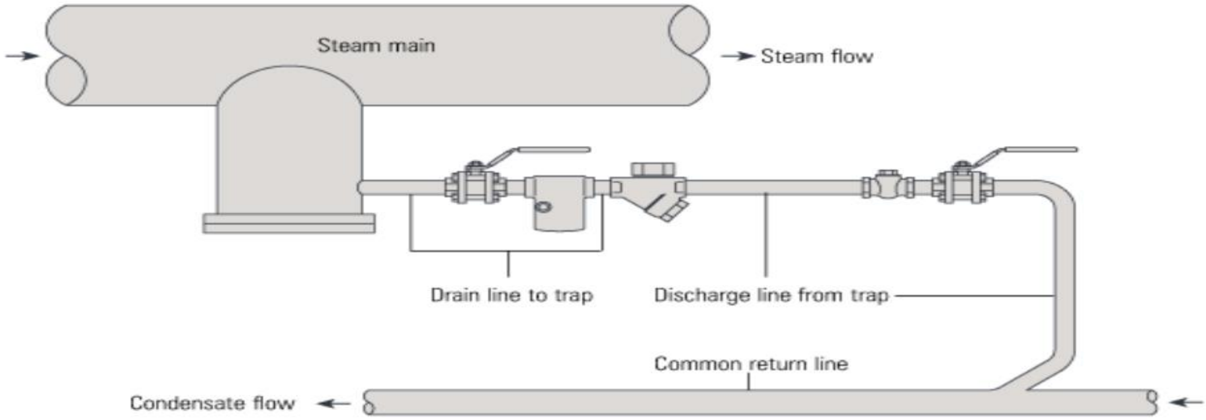

Figure 9. 1Steam and condensate line

For this particular factory the condensate that comes from point of use like bottle washer is taken back to the boiler feed water tank and increases the temperature of feed water to 55^0C. The condensate recovery line and parts of the factory has been maintained (insulated) properly but a point at heat exchanger (bottler washer) is leaking in small amount and the factory has to insulate it or has to change parts of the point specified.

9.6. Steam Traps

Steam trap is the most important link in the condensate loop because it connects steam usage with condensate return lines. It allows steam to reach its destination in dry a state to perform its task efficiently and economically. It may discharge condensate at steam temperature or below steam temperature.

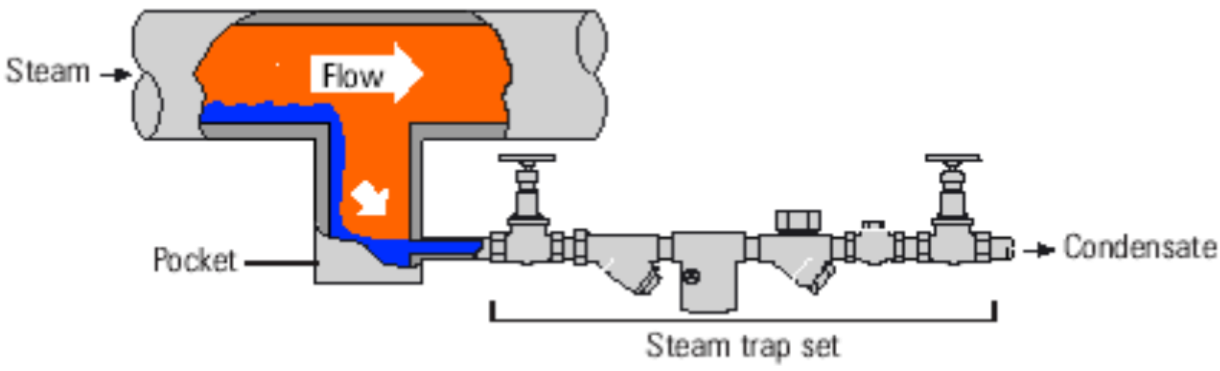

Figure 9. 2 Steam Traps

Some steam trap points in Ambo Mineral water Factory has problems. For example points on heat exchanger around bottle washer need considerations as they are leaking steam and condensate(in little amount).Hence, factory has to maintain this points in order to maximize operating efficiency of steam strap.

9.7 Summary—List of Energy Conservation Measures of Steam Distribution System

Table 9 3 Summary—List of Energy Conservation Measures of Steam Distribution System

S/N	Energy Conservation Measure	Annual Saving (ETB)	Investment Cost (ETB)	Simple payback period	Rank
1	Lines surface insulation	15,128	3,900	0.26	1
2	Line Insulation, Maintenance and Replacement (steam leakage)	56,519	64,000	1.13	2

9.8 Conclusion Remarks

In general, in order to improve energy performance of steam distribution lines, the factory has to apply the energy conservation measures of surface losses and steam leakage respectively and also need to conduct regular inspections.

CHAPTER 10

ENERGY ACTION PLAN OF AMBO MINERAL WATER FACTORY

10.1 Introduction

A detailed action plan is important to ensure a systematic process to implement energy performance measures. The action plan needs regular update to reflect recent achievements and changes in performance of the systems. In this section the short term, the medium term and long term action plan which are technically and economically feasible for Ambo mineral water factory are discussed.

10.1.1 Short Term Action Plan

This term plan is a continuous plan may be within a week, month, quarter or a year. This plan can be done with less or without cost just by employees of the factory to minimize or avoid energy and to improve the system efficiency through improved maintenance program.

Table 10 . 1 Short term action plan

S/N	Activity	Action Term
1	Cleaning motors in the factories	Short Term
2	Cleaning boiler surface and its surrounding regularly	Short Term
2	Checking proper functioning of steam traps	Short Term
3	Regularly remove scale from boiler waterside	Short Term
4	Turning off lights when not needed	Short Term
5	Cleaning air compressor filter	Short Term
6	Removing water and other dirt materials near the equipments	Short Term
7	Turn off motors when unloaded	Short Term

10.1.2 Medium Term Action Plan

The medium term action plan is done to improve the performance of equipments or parts, or may be modifications of existing equipments. It needs less or medium cost and can be conducted by the staff of the factory.

Table 10. 2 Medium term action plan

S/N	Activity	
1	Insulating steam distribution lines	Medium term
2	Insulating Boiler surface	Medium term
3	Installing flow meters, pressure gauges	Medium term
4	Clean the shell of the boiler	Medium term
5	Maintaining conveyors	Medium term
6	Rewinding old motors	Medium term
7	Maintaining air compressor and its distribution lines	Medium term

10.1.3 Long Term Action

The long term plan is a plan that needs professionals like Engineers, Managers, Logistics, Economists and capitals to be done which bring the efficiency and profit for the factory in long term operation.

Table 10. 3 long term action plan

S/N	Activity	Action term/period
1	Replacing existing inefficient and old motors	Long term
2	Repairing water treatment plant	Long term
3	Replacing existing inefficient and old pumps	Long term
4	Purchasing combustion analyzer	Long term
5	Purchasing and installing power analyzer	Long term

10.2 Energy Action Team

Energy Manager is not always an expert in energy and technical systems. In order to assess energy performance, plan and implement action plans which are planned in short term, medium term and long term to improve energy efficiency energy action team is important. The tasks to be accomplished by energy team are executing energy management activities and it helps to integrate energy management activities in the factory. The size of the energy team will vary depending on the size of the organization. In addition to the Energy Manager who leads the team and dedicated energy staff, the team can include a representative from each operational area that significantly affects energy use of the factory like:

- Operations and Maintenance
- Engineering
- Purchasing
- Utilities
- Suppliers

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusion

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. Hence this thesis research has discussed on energy audit of Ambo Mineral water factory. The energy consuming, inefficient and old systems of the factory like electric motors, boiler, water pumps, air compressor and steam distribution lines were examined for their energy performance, and energy conservation and measures were identified.

According to 2018(G.C) energy bill data, the factory paid for both thermal energy (fuel oil) and electrical energy 5,953,395.00 Birr and 1,008,685 Birr respectively. To analyze the factory's energy consumption and specific energy and to give conclusion the 21-months data (October 1, 2017—June 1, 2019) energy (diesel oil in liter and electricity in kWh) and benchmark data were collected and used.

Based on the study, most of the motors of the factory have motor loading of less than 50%.By replacing the oversized and old motors, annual energy cost of about 46,000birr can be saved. From water pumps audited, replacing them can save annual energy cost of around 128,700Birr.The results obtained from the detail audit of air compressor system indicated that its efficiency is 38.7 % and the loading factor of the motor is 75.6%.

From the detail energy audit of the boiler, the input and out mass of combustion system of the boiler calculated were 27.22kg and 27.23kg respectively. The heat input, heat output and loss heat of the boiler calculated were 2,760kW, 2122kW and 711kW respectively. The calculated combustion chamber efficiency of the boiler was 75%.But the boiler's thermal and overall efficiencies were 74.2% and 72.2% respectively. Possible energy conservation measures identified from detail energy audit were: Repairing feed water treatment plant(cost of energy saved will be about 267,800Birr) and insulating boiler surface(cost of energy saved will be around 26,300birr,).

Finally, the energy audit on steam distribution lines indicated that around 71,700 birr can be saved annually. For this particular factory the condensate that comes from point of use (bottle washer) is taken back to the boiler feed water tank and increases the temperature of feed water to 55^{0}C. Some steam trap points in Ambo Mineral Water Factory have problems,(points on heat exchanger around bottle washer) and need considerations in order to maximize operating efficiency of steam strap and as a whole.

In general, this thesis research has assessed the energy use of the Ambo Mineral Water factory, identified and recommended energy conservation opportunities and measures through energy audit. At the end, short term, the medium term and long term action plans which are technically and economically feasible for Ambo mineral water factory were discussed to implement energy performance measures.

11.2 Recommendations

In order to improve the energy consumption efficiency of the Ambo Mineral Water factory, the following recommendations are important and need to be applied.

- Replacing oversized and old motors of the factory
- To improve the energy performance of water pumps and their systems, the factory has to follow each and every points of operation and has to replace low operating water pumps.
- Regular cleaning of compressor inlet ducts, filter and rearranging air distribution lines so that the distance between air compressor and points of use are minimized and the losses are reduced.
- Repairing water treatment plant and insulating surface of the boiler.
- The factory has to apply the energy conservation measures of steam leakages and surfaces identified and also need to conduct regular inspections.

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APPENDICES

Appendix A

Monthly Factory Energy consumption

Billing Period	RGB, Electricity Consumption(kWh)	# Liter of Fuel Consumption
October 1,2017	133,200	22,729.50
November 1,2017	115,200	19,823.25
December 1,2017	113,400	13,747.50
January 1,2018	190,783.00	29,517.00
February 1,2018	97,200	21,463.50
March 1,2018	107,456.40	15,447.00
April 1,2018	38343	26,451.75
May 1,2018	97200	36,080.25
June 1,2018	265400	35,090.25
July 1,2018	48600	18,917.25
August 1,2018	57600	26,169.00
September 1,2018	54000	27,570.75
October 1,2018	176,400	20,808.75
November 1,2018	126280.8	20,774.25
December 1,2018	123918.792	19,380.00
January 1,2019	198,417.26	28,563.00
February 1,2019	216,000	25,780.50
March 1,2019	133,500.00	27,221.75
April 1,2019	130,750.86	22,298.25
May 1,2019	134,366.94	26,297.25
June 1,2019	156,941	26,036.25

Appendix B

Factory ‘Ambo Mineral Water’ production Data

Billing Period	RGB, Liter of water Produced
October 1,2019	2,068,045.50
November 1,2019	2,319,463.00
December 1,2019	1,317,719.00
January 1,2018	2,759,522.00
February 1,2018	2,513,595.50
March 1,2018	1,637,695.50
April 1,2018	2,251,614.00
May 1,2018	3,062,695.50
June 1,2018	3,015,053.00
July 1,2018	1,954,767.50
August 1,2018	2,269,768.50
September 1,2018	2,168,090.00
October 1,2018	2,298,420.50
November 1,2018	2,396,878.50
December 1,2018	2,150,999.50
January 1,2019	3,114,964.50
February 1,2019	2,313,145.50
March 1,2019	2,182,872.00
April 1,2019	1,771,588.50
May 1,2019	3,197,776.00
June 1,2019	2,404,659.00