INVESTIGATION ON ENERGY UTILIZATION PERFORMANCE AND DEVELOPMENT OF ENERGY MANAGEMENT MODELING PROGRAM FOR ZEWAY CAUSTIC SODA SHARE COMPANY

By:

Eskedar Alem

A Thesis Submitted to

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Advisor: Dr. Gezahegn Habtamu (Assistance Professor)

A Thesis Submitted to

Thermal and Aerospace Engineering Program of School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University in Partial Fulfillment of the Requirements for the award of the Degree of **Master of Science in Thermal Engineering.**

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APPROVAL SHEET OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Esikedar Alem have read and evaluate his/her thesis entitled *"Investigation on Energy Utilization Performance and Development of Energy Management Modeling Program for a* zeway Caustic Soda Share Company*"* and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Thermal and Aerospace Engineering.

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External Examiner	signature	date

CANDIDATE DECLARATIONS

I hereby declare that the work, which is being presented in the thesis, entitled "Investigation on energy utilization performance and development of energy management modeling program for a factory; a case of Zeway Caustic Soda Share Company Quicklime Production System". In partial fulfillment of the requirements for the award of the degree of Master of Science in Thermal and Aerospace Engineering is a reliable record of my own work carried out from October 2018 to August 2019 under the supervision of Dr. Gezahegn Habtamu.

I have not submitted the matter embodied in this thesis for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Eskedar Alem Abuhay ______________________ ______________________

Name of the student signature date

This is to certify that above declaration made by the candidate is correct to the best of my knowledge. This thesis has been submitted for examination with my approval.

Dr. Gezahegn Habtamu ______________________ ______________________

Advisor Signature Date

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LIST OF SYMBOL AND ABBREVIATION

List of Abbreviation

AAFR	Actual air-fuel ratio
TAFR	Theoretical air-fuel ratio
A	Area
MEC	Monthly Electricity Cost
MCF	Monthly Fuel Cost
EA	Excess Air
MEEI	Monthly electricity energy intensity
Kg	Kilogram
Kj	Kilo Joule
GCV	Gross Calorific Value
CUSUM	Cumulative Sum
HFO	Heavy Fuel Oil
MTEI	Monthly Thermal Energy Intensity
TAFR	Theoretical Air-Fuel Ratio
ZCSSC	Zeway Caustic Soda Share Company
LHV	Lower Heating Valve
MTR	Monitoring, Target and Reporting
EMP	Energy Management Program
Wab	wet ashless HFO
QL	Quicklime
Lm	Limestone Pebble

List of Symbol

R	Thermal resistance (K/W)
Q	Heat Energy (W)
Γ	Humidity Factor
I &O	Input and Output
η	Efficiency
kWh	Kilo Watt-hour
$\dot{m}$	Mass Flow Rate(kg/sec)
ρ	Density (kg/m^3)
H	Enthalpy (kJ/kg)
γ	Humidity factor
T	Temperature(℃)
℃	Celsius
Φ	Relative humidity
C_p	Specific Heat (J/(K kg)
$\dot{V}$	Volume flow rate(m^3)
$\dot{m}_{df}$	Mass of dry flue gas(kg/sec)
MW	MegaWatt
P	Pressure (pascal)
Φ	Relative humidity
V	Speed(m/sec)
R	Radius(m)
μ	Dynamics Viscosity(kg/m.s)
α	Thermal Diffusivity (α,m^2/s)
K	Thermal Conductivity (w/m.k)
H	Convection Coefficient (W/(m^{2}K)
V	Kinematic Viscosity (kg/m.s) m^2/sec
Pr	Prandtl Number
ε	An Emissivity Of The Constant
σ	Stefan−Boltzman Constant

Nu	Nusselt number
B	% of limestone
X	% of quicklime
L	Length
Re	Reynolds number

SUBSCRIPTS

Amb	Ambient air
A	Air
Fg	Vaporization of water
Fl	Flue gas
f	Flue
Comb	Combustion
Ql	Quicklime
Ls	Limestone
H_2O	Water
Fp	Fuel pre-heating temperature
Rad	Radiation
Conv	Convection
Cond	Conduction

ABSTRACT

Evaluation of the energy utilization performance of a factory is important to developed energy Management modeling program that will help any factory to properly monitor its present and future energy consumption, energy budgeting and also identify energy saving opportunities. This paper has investigated the thermal and electric energy utilization performance of Zeway Caustic Soda Share Company quicklime production systems by studying its four year energy consumption data. In addition, the paper has investigated the thermal energy performance of the heavy fuel oil fired furnace and lime pebble burning kilns. The paper also discusses a standard energy efficiency analysis method developed for an industrial kiln & furnace by direct and heat balance method using actual data collected from the control boards and log sheets of Zeway Caustic Soda Share Company . The efficiency of the kiln was found to be 63.08% by the direct method using actual data collected from the control boards and log sheets of Zeway Caustic Soda Share Company. The energy efficiencies of the furnace were calculated applying the developed standard method and the results obtained were in the 52.8% by direct method and 55.8% by indirect heat balance method using the 12% actual oxygen content of air in the furnace taken from the control panel.

The efficiency of the furnace was recalculated by considering keeping the oxygen content in the combustion air at 15% and it was found to be 72% by the indirect method. The total energy and cost-saving potential of that can be obtained for keeping the oxygen content of combustion air at 15% were found to be 501.9 kW. Microsoft Excel and Minitab software 14 were used for analyzing the data. The paper also has developed regression models.

Keywords: *Regression Analysis, Baseline Model, CUSUM Analysis, Energy Modeling, Energy Utilization Performance, limekiln, Furnace efficiency, heavy fuel oil.*

CHAPTER ONE

INTRODUCTION

1.1 Backgrounds of the Study

Energy is a major input for the economic development of any country. Electric and thermal energy is the most useful primarily energies used for day-to-day domestic and industrial activities. Energy performance is the amount of energy actually consumed (or estimated to be necessary) to see the different requirements associated including elctricity and heavy fuel oil. They are usually generated by burning different amounts of fossil fuels like coal, petroleum coke, furnace oil (Mazut), heavy fuel oils, natural gas, etc. Besides, both electric and thermal energy demand for domestic as well as industrial activities nowadays is being supplemented or complemented with renewable energy resources such as solar, wind, biofuels, biomass, geothermal, hydropower, etc. The use of energy resources in the factory required to be reduced by managing the utilization of fuel oil and electricity which is termed as energy management. However, the management of electric and thermal energy generated from renewable or nonrenewable resources by industries is equally important in line with the effort in generating them since it provides useful information on the past and present energy utilization performance patterns and energy bills [1]. Energy management is also essential for predicting future energy demand and energy budgeting by an industry. Moreover, energy management also helps industries to maximum profit (minimize cost) and enhance competitive position [2].

Many industrial facilities in the world present very high-energy consumption due to the high energy demand of their specific process utilized to produces different products. Various energy-efficient devices are being developed and utilized year after year in industries for reducing energy consumption and making the industries profitable or competitive in the market.

In our country, energy auditing one of the application areas of energy management was given proper attention by academic researchers and government bodies.

The quicklime production facility is the sole supplier of quicklime which is used as raw materials for various other industries in world such as cement industries, sugar industries, construction industries, beverage industries, etc. Mazut is a heavy or viscous fuel that is imported from abroad. The factor uses electric energy for thinning the viscosity of Mazut and drives various kinds of electrically driven machines in the production system of quicklime. This factory is currently under bankruptcy primarily due to its huge heavy fuel oil (Mazut) energy consumption bought by hard currency. It is uses Energy with less efficient energy management. It requires increasing the energy performance of the factory by developing the energy auditing system. An energy audit conducted in a typical lime kiln showed that only 56.8% of the heat supplied was used to decompose. The remaining 43.2% of the energy was irreversibly lost through the kiln shell (5.8%), flue gases (32%), product (2%) and miscellaneous losses (which accounts for 3.4%) [3]. Therefore, it is necessary to minimize this energy loss through the study of reaction parameters governing the calcination process. This shows a high amount of fuel is required for the burning process of limestone pebble in the kiln. The production of lime begins with the quarrying and crushing of limestone. Lime is a very important product in our lives, and we can find it everywhere nowadays in so many distinctive working areas such as flue gas desulphurization, metallurgy, construction, sugar refining, glasses, water treatment, sewage treatment, and manufacturing of paper and pulp [4].

Lime is produced by thermal decomposition of limestone in a shaft or rotary kilns. Burning lime or decomposition of limestone is an endothermic process, in which the kinetics of the burning process strongly depends on temperatures [4, 5].

Energy conservation is necessary for Industrial energy efficiency sustainability due to growing concerns over the environment and the scarcity of resources [6]. Most industrial processes are characterized by low energy efficiency, which indicates that there are significant opportunities for improving energy efficiency in any sector [7]. Production levels should not be affected, only the amount of energy and the expense incurred in generating that production. This implies a reduction in energy costs and consequently increases profitability.

But, the other aspects of energy management program such as energy modeling monitoring, targeting, and control is given less emphasis. Hence it would be necessary to evaluate the energy performance of industries continually and at least understand their position in terms of their trends of past energy utilization, energy bill, prediction of their future energy consumption and energy budgeting before conducting detail energy conservation and audit analysis.

Almost all industries in Ethiopia such as pharmaceutical facilities, food industries, sugar industries, cement industries, textile industries, quicklime, and brewery industries utilize electricity obtained from the national grid-primarily generates by hydropower plants, and thermal energy by burning fossil fuels imported from abroad to run their production equipment.

Generally, the energy consumption of this factory per unit of production is unknown and its energy consumption is increasing steadily which is reported to be the primary contributor to its loss of profit. Besides, no proper maintenance, replacement of outdated energy equipment, energy audit, and energy conservation study has been done at this very important quicklime producer facility since its establishment.

The problems of the factory observed during the site visit are

- The furnace consumes a huge amount of heavy fuel oil
- Operators of the factory machinery work with their own experience in running the production system, for instance, visual inspection of exhaust smoke for adjusting the air-fuel ratio in the furnace.
- The factory does not have personnel skilled in energy management
- Measurement using instrument but not detail energy audit was conducted at the facility.

The problems listed above need an immediate solution by a detailed study of the energy utilization of the quicklime production system of the factory to identify its energy performance and also predict its future energy requirements.

1.1.1 Background of the Factory

Zeway Caustic Soda Share Company is a public enterprise that is found 160 km away from Addis-Abeba in the East Shoa Zone in Oromia region. This company was established in 1990 to produce caustic soda from trone, quicklime, and water as the main raw material. It has fully functional caustic soda and quicklime production plants.Present the production of caustic soda is suspended due to three primary reasons: poor quality of raw material for production trona; low concentration of the produced caustic soda and its brownish color.

The factory is producing quicklime in a pocket of 72 kg. The factory also sells fine or grounded limestone as chicken feed, which is a byproduct in the crushing of limestone into a smaller pebble. The major production step of quicklime is crushing of limestone into smaller pebble with sizing in the range 2-3cm: burning these pebbles inside a rotating kiln of 42 m length between burning pebble from 950 to 1100℃ to ambient temperature, grinding the roasted and cooled pebble & bagging the quicklime in 72 kg. The factory uses flue gas which is generated during the combustion of mazut (fuel oil) after mixing it in a furnace with sucked by a dissipated electric motor.

The Mazut is a viscous fluid and it is pumped to the fuel burner after reducing (thinning the Mazut) the viscosity of the Mazut by dissipated electric energy in an electric furnace. Electricity and Mazut is the major sources of energy for the factor for the production of quicklime. the energy consumption of the factory is rising from year to year considerably.
However, during a visit to zeway caustic soda share company factory observed that most of the lime industry lacks appropriate equipment maintenance management system .Quicklime industry equipment is not properly used and it is old. Generally, this industry is not significant and not using new technology. The reason for the industry firstly star for the production of caustic soda and it is a demerit. However, one engineer creates a new idea to done quicklime production.

1.1.2 Quicklime Production Process

Quicklime is obtained by 'burning' or heating calcium carbonate, which occurs in natural limestone deposits. It is a fine powder .The basic processes in the production of lime are: (1) quarrying raw limestone; (2) preparing limestone for the kilns by crushing and sizing; (3) calcining & burning limestone. Figure 3.1 shows the general describes the lime production process. These main general processes are discussed as follows.
Countercurrent flow of the charge of limestone pebble in the kiln and the flue gas generated due to the combustion of fuel is suitable for the production of hard burnt, low reactive lime. The raw material of limestone pebble burns at the end of the side kiln. Releasing the fuel combustion at the one side of or end of the burning zone, where the kiln charge limestone pebbles are already completely calcinated. The combustion gases in counter-current then preheat it before reaching the burning zone. In the burning zone, the material is calcined and - depending on the product specification, utilizing fuel introduced together with primary combustion air through the radially

arranged burners. Cooling air is introduced at the discharge of the kiln to cool the product in a counter-current manner.

The quicklime production process can be expressed in scientific terms as follows:

$C_aCO_3 + \text{heat} \rightarrow C_aO + CO_2$

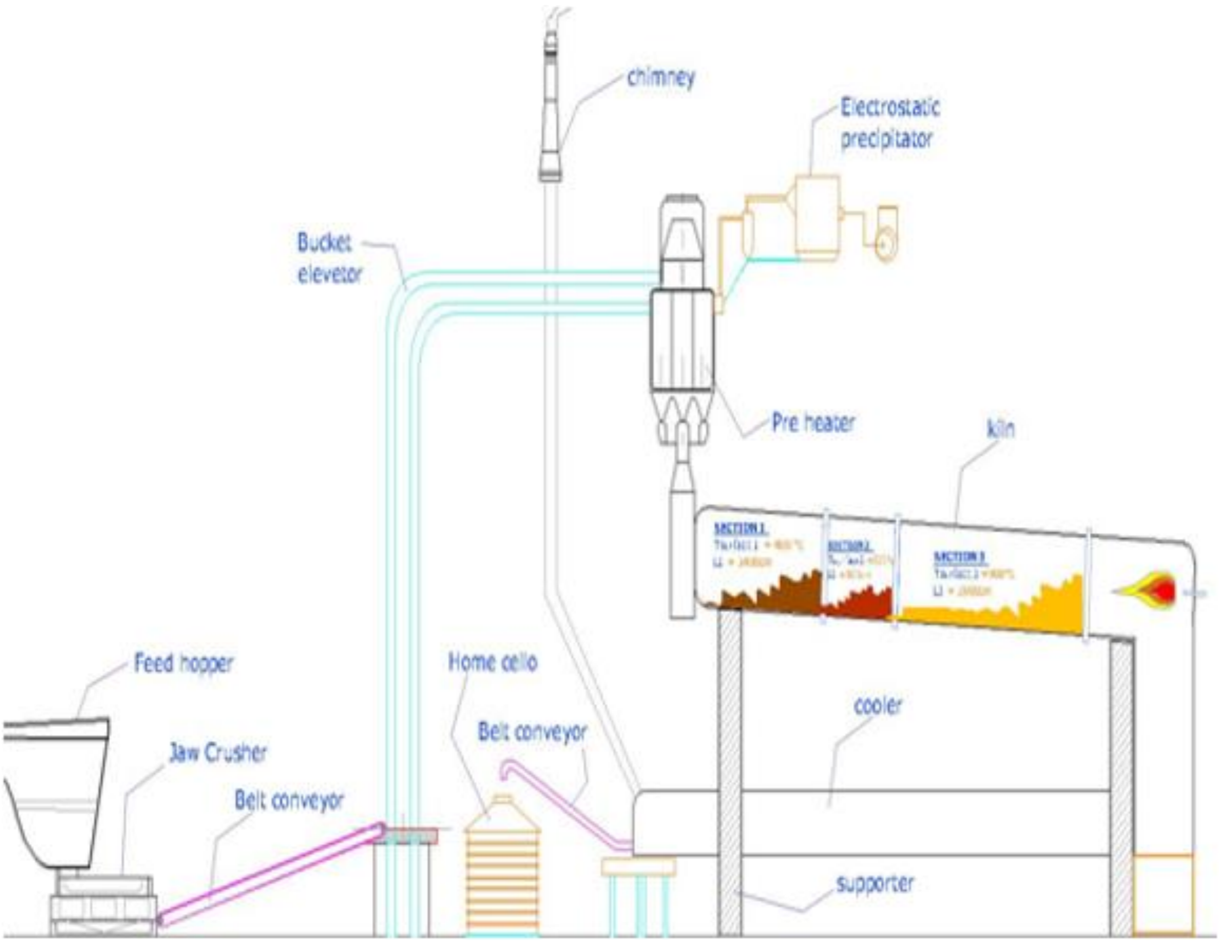

Figure 1.1: Processes Flow Diagram and Major Unit Operation

Transport of Raw Material

The production process of lime starts with limestone supply, involves such as an explosion of rocks, transportation the raw material from quarries with dump trucks, crushing the rock on-site the most common raw materials used for lime production are limestone. The major component of the raw materials, the limestone, is usually extracted from a quarry very close to the plant. Limestone provides the required calcium oxide. Active lime is produced from limestone, dolomite and other minerals with high calcium carbonate content.

Primary Jaw Crusher

Limestone crushing action is the aboriginal important action before limestone abstracts are burned. It is mechanical production equipment used to crush the quarrying limestone. The limestone is very large and needs to be reduced into small size from 2-3 cm of limestone pebble before feeding it into a rotary kiln. The quarrying limestone is taken from its ore and washed with water and it enters into primary jaw crusher.

Figure 1.2: Primary Jaw Crusher

Belt Conveyor

The belt conveyor is the chain used to transport the small size of limestone pebble to sieves and rotary kiln. The sieves are equipment that is used to separate limestone pebble from dust. The limestone dust is used to prepare food for chicken and limestone pebble is directly entered into the rotary kiln to produce quick lime.

Furnace Fuel Oil

The furnace is a combustion gas production equipment used to burn the furnace oil at the beginning to the center of the rotary kiln equipment. The furnace is the core equipment of the rotary kiln since it is the point at which the combustion of fuel takes place in the form of flame. Furnace efficiency of the lime industry depends on fuel consumption, the ability of combustion in the mixing of air to fuel ratio. Because of the moisture content created in the furnace due to entry of air through the fissures of the kiln, the air to fuel ratio will not be proportional which results in more fuel consumption and a low amount of air is used in the furnace.

Raw Materials Storage

The raw materials that are moving sideways through a belt conveyor from the crusher department are stored in the raw material storage (silo). They are deposit in several loads in the store using a stacker. The stacker has used stack raw materials in several loads in a store. After the raw materials are arranged in loads the bond scrapers used for standardizing of particulate materials at the longitudinal store and for the conveyance of the normalized materials from the loads to the outgoing conveyor.

1.1.3 Energy Saving Rotary Lime Kiln Process

The kiln is mechanical production equipment used to mix limestone pebble and combustion of the fuel with air, which is, called calcination or burn the two inputs. ZCSSC kiln is the rotary type where limestone pebble is raw material entered into the beginning side of the kiln (preheating zone) and discharged from the outlet side of the kiln within the opposite side of air-fuel combustion. The kiln is a very long pipe that has 42m length, 1.6m inner diameter, and 1.8m outer diameter. Between outer pipe and kiln, there is vacant space that leads more fuel oil consumption due to this to create wastage since when infiltration atmospheric air is entered into the combustion of fuel, it creates moisture inside a rotary kiln and the fuel will not burn properly. Generally, there are different parts of the kiln. Such as;

- Preheating zones
- Combustion (calcination) zone and

- Cooling zone. The three parts are maintained at a different temperature**.**

The long rotary lime kiln has the characteristics of simple structure and stable operation. It increases the length of the rotary kiln cylinder to improve the preheating effect, and after preheating, the limestone is entering into the calcination zone for decomposition; the limestone pebbles feeding size can be 2-3 mm and the temperature is the same atmospheric air.

The energy-saving rotary lime kiln has an advanced structure and stable operation. It assumes the horizontal preheater with low-pressure loss, which can effectively improve the preheating effects. There are various processes for the active lime production, mainly including advanced Preheater-Rotary kiln, horizontal cooler energy-saving process. The selection of the lime process is affected by many factors, such as the activity requirement, the fuel, the limestone sizes, production capacity, and environmental-protection requirement.

Figure 1.3: The Factory kiln and Cooler system

Packing and Loading

The department is used to packing the result of quicklime to be sold to the customers by transporting it to different market place. It is packed through two systems packing unit and bulk loading units. In the packing unit, the quicklime is packed using a rotary bag packing machine through manual bag feeding. Transport of bags to the loading through roller conveyor and belt conveyors equipped with brake and speed controller. Dust filtering unit is bag filters or any other unites. The bulk loading unit uses a loading device with a brake and speed controller.

1.2 Problem of the Statement

Most factories in Ethiopia have the problem of proper utilization of energy. They did not know their energy consumption patterns in a well-defined manner by performing an energy management program. As a result of this huge utilization of energy the factory is unprofitable and is running by subsidy from the government of Ethiopia. Thus, this thesis focus on investigating the past energy utilization & bill trends, energy performance of the major energy equipment in the quicklime production system and developing an energy management modeling program for ZCSSC that will help it in predicting and controlling its future energy utilization and budgeting.

The main problems of the factory include:

- Unknown heavy fuel oil-fired furnace efficiency
- has no mechanism for predicting its future energy demand & budgeting,
- Infiltration of atmospheric air along the length of the kiln through the opening which may affect the air to fuel ratio and may cause inefficiency combustion due to moisture and excess air.
- has no energy management program that can control its and monitors, targeting and reporting (M, T & R) mechanisms that will help its present and/or future energy utilization for its production of quicklime and reducing its energy consumption.

1.3 Objective of the Study

1.3.1 General Objective of the Study

The general objective of this work is to investigate the energy utilization performance of ZSSC in terms of energy consumption and energy billing in the production of Quicklime for developing an energy management program (EMP).

1.3.2 Specific Objectives of the Study

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

- Review the electric and thermal energy consumption patterns and associated energy bill in the production of lime by the factory for the last four years.
- Identify the major energy-consuming systems in the lime production system, analyze their energy performance, and suggest possible energy conservation opportunities.
- conduct an economic analysis of the suggested energy conservation opportunities
- developed energy management program (EMP) for the factory by applying cumulative sum analysis using Minitab 14 software and Excel 2016 (analysis of variance) that can be used for Monitoring, Reporting and Targeting (M ,R &T) and predicting future energy demand of the factory.

1.4 Significant of the Study

The study will determine the energy consumption of the factory in lime production as per the status of raw material scientifically (qualitatively and quantitatively).

- Identify the present and the past energy consumption profile and corresponding energy bill,
- Identify the furnace &kiln efficiency of combustion of heavy fuel oil the relationship between the quantity of energy and the quick lime production,
- Improve the energy performance and the energy management means of the factory,
- Identify wasteful energy use and take action to reduce or illuminate that waste;
- Develop a document on the energy management program mainly energy Monitoring, Reporting and Targeting (M ,R &T)

Documentation that is very useful for the factory to be profitable in the future if it reduces its Mazut (heavy fuel oil) consumption, customer satisfaction, improves productivity and competitiveness in particular. The profitability of one company has a great contribution to firstly the owner itself, secondly employees and finally the country. At the end of this project, the factory will be properly managed and save energy.

1.5 Scope and limitation of the study

This thesis confined only to the study of thermal and electric energy use in the quicklime production process. This thesis focuses to investigate the energy utilization performance of the lime industry on the evaluation of the energy consumption using excel / Minitab 14 software (Analysis of variance software). This includes combustion furnace efficiency of analysis, energy modeling, and evaluation of the energy performance of limekiln performance. Numerical results will help to conduct the validation of saving and the energy performance of the industry. The study encompasses reading relevant literature, collecting, and analyzes data from the factory for energy consumption, monitoring, accounting, and management in the company.

This paper study has several limitations; primarily that it did not systematically or M&T software products and participating in a factory within energy information of the system provider were recruited through a suitability sample Monitoring, Reporting and Targeting (M ,R &T) practice. Since obtaining complete data for the past four years was difficult because there are four shift operator times and downtime of the factory due to the stoppage. Almost all workers and operators were busy due to continuous production quicklime, it creates some challenges to discuss, and gain required information from operators and teams.

1.6 Organization of the Thesis

The thesis study organized in six chapters and the outlines described as below:

Chapter1: Describes introduction, statement of the problem, objectives, significance, scope, and limitation are explain briefly.

Chapter2: Describes literature review mainly presents works of literature supporting my thesis study such as the overview of research work done on causes and remedies of energy wasteful in-process production, background of the company, energy utilization performance study, amount of production relation between of energy consumption study and finally discuss related ideas about energy conservation opportunity.

Chapter 3: Describes research methodology, this part refers to a way of a thesis that is done including the method of data collection and analysis, software to study energy analysis and required material for measurement sample data.

Chapter 4: describe investigation on combustion of heavy fuel oil and kiln performances

Chapter 5: an investigation of energy utilization performance and energy modeling

Chapter 6: Describes results discussion and

Chapter 7: conclusion and recommendation, data validation of statistical software Minitab 14 and discussion and interpretation of the results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Review about the advantage of energy performance in Ethiopia quicklime industry, techniques of Cumulative sum and performance energy model. The literature is available from electronic media, journals, and books as primary data. Secondary data are referred from previous and related research studies, existing statistical data and interviewing in quicklime industry workers who may concern. The relevant literature was discussed in below.

In this chapter, the literature available related to this study is reviewed within the preview of the present investigation. Review of a number of in these sections, works of literature on Energy modeling, combustion of heavy fuel oil, and kiln performance are reviewed.

Data collection is an activity or way of gathering information from a different research paper. It enables a team to formulate and test working assumptions about a process and develop information that will lead to the improvement of the key energy performance of the factory. It also improves decision making by helping focus on objective information about what is happening in the process, rather than subjective opinions

Literature is a system of obtained relevant data from direct sources and data collected from the communities. The user uses a different mechanism that helps to obtain the most critical and powerful information in an easy and suitable way by using; observation method, interviews of the skilled person and experimental test and focus group. Form those methods of primary data collection, the first two help in this study that is direct observation and interview. Observation becomes a scientific tool and the method of data collection for the researcher, when it serves a formulated research purpose, is systematically planned and recorded and is subjected to checks and controls on validity and reliability.

In this type of data collection, data gathered indirectly from different sources. Such as reference books, different journals and article papers, manuals and internet sources.

2.1.1 Energy Modeling

Giacone et al., (2008) reported that energy management has a significant effect on the industry to obtain energy saving by using different technique linear regression chart plot and CUSUM. The aim of the studied statistical control process technique to make but not detail energy management. CUSUM is the main tool to analyze energy consumption state, improve on energy efficiency and reduced energy cost depends on the historical and monitoring phase. As a result of the positive relationship between energy and production, which is measured R^2 (correlation coefficient goodness of fit. In other words, it measures the success of the regression in predicting the values of the dependent variables [24].

Harini and Surekha (2014) investigated successfully used Regression method for predicting of Fine-Grained Soils and Stated Multiple linear regressions (MLR) to determine the relationship between two or more independent variables and a dependent variable by fitting a linear equation to observed data. Every value of the independent variable is associated with the value of the dependent variable [45].

Tanaka (2008) studied measuring energy efficiency performance in steel industries by using different methods to estimate the energy efficiency and collected data. This paper studied was significant to reduce energy loss and to determine specific energy consumption. The aim of the studied was to explain energy efficiency performance and advantage and disadvantage the political implication process in police makers. This concluded using energy in industry 2.4 GJ [46].

Puranik, (2007) studied measurement energy performance and evaluating in cast iron steel industry for few samples by using cumulative sum (CUSUM) in statically and regression methods. The purpose of the paper was to compare CUSUM and traditional control charts with providing improvement of the successful encompassed energy performance. Show the result of this paper CUSUM quality control for monitoring energy use performance to improve energy consumption and easily control the fuel consumption a similar manner to electrical and detail explain but not Minitab software the CUSUM quality control for regression analysis[1].

Adiana et al., (2007); studied energy management technology to improve energy efficiency and saving energy consumption in the cement industry of Columbia. This paper uses different methods like strategy decision, implementation of the energy management and operation of the system government. The result of this paper shows a reduction of 4.6% electric energy consumption and a similar 6% saving potential for energy consumption. They concluded based on collected data of the energy efficiency indicator and analysis cause of deviation etc[57].

Afkhami et al., (2015) estimate energy consumption with energy management for increasing the energy opportunity by using the CUSUM technique method for process monitoring of the chart, collected data, energy-saving measuring in the cement production industry. Show the result of this paper to increase the thermal and electrical energy with decrease the energy cost of from 10.4% to 76% in 2008 to 2010 respectively and improve 22.6% to 19.9% of the thermal and electrical specific energy consumption controlling by using CUSUM method [49].

Siebert et al. (2015) studied energy efficiency in each industry using energy managers based on energy management. The efficiency of Energy used to estimate energy consumption and site a side of energy efficiency at an industrial facility. The utilization of the energy of management using different methodologies like select EEI, analysis EEI, and other CUSUM analysis shows an improved energy performance. It allows the industry to compare the efficiency but at the same time keep data privet [50].

2.1.2 Combustion Heavy fuel oil (or Mazout)

Cost et al., (1991) studied the combustion of Heavy fuel oil spray in furnace and nozzle angle using experimental and simulation in computational fluid dynamics. The aim was to improve in mixing, droplet evaporation & chemical reaction and combustion in the burner region. They found that increase secondary air swirl (0.9-1.3), increase in combustion excess air (15 - 25%) and NO_2 emission were negligible collected fuel oil versus spray angle variation is not significant. They concluded that increasing the combustion excess air increases thermal efficiency [15].

Elbaz et al., (2018) investigated the combustion characteristics of heavy fuel oil in terms of droplet formation and oxidation of the particulate matter. The main purpose of the paper was to study the co-flow air around a droplet and thermal profile along with droplet on the cenospheres characteristic and the number of the specific phase identified. The researcher study in an analytical and experimental method for study the falling droplet experiment and suspend droplet experiment. The article was an analysis of the energy-dispersive various burning phase. They concluded the influence of combustion heavy fuel oil range diameter of pipe from 290-422, velocity and temperature of the furnace was found to depend on the delay of resident time and droplet size after ignition [38].

Azimiet et al., (2018) studied evaporation of heavy fuel oil droplet under atmospheric pressure. The comparison of similarity and the evaporation process details identified using internally about conclusion, the recommendation for the future suggestion to reduce energy loss, increase energy performance. The temperature of it droplet used to predict the initial condition of the thermal behavior component by calculated different parameter like density, thermal conductivity and viscosity depend on molecular weight. Generally, heavy fuel oil was solving the evaporation droplet of using a complete governing equation [39].

Wu et al., (2007) investigation heavy fuel oil combustion with high temperature preheated air in the steel industrial test furnace. The aim of the paper develops and regenerative burner fired system by using the experimental method. They found the temperature of air preheated 1200 ℃ evaluated on different burner equipment since increased heat transfer to furnace wall and reduction nitric oxide applied directly injected & mixing fuel into a furnace by buoyant force [40].

Park et al., (2015) studied heavy fuel oil property spray characteristics in the Marian engine injector using Experimental equipment and condition were used measurement properties heavy fuel oil required for studying the furnace efficiency analysis. They founded specific gravity tests that explain the fuel density increase in the experimental test. They concluded heavy fuel oil was physical property characteristics of vary with fuel temperature and determine heavy fuel oil general properties with curves, but the range of property change importance of the liquid property [18].

Mikaniki et al., (2018) investigated atomization heavy fuel oil in the chemical industry by pressured swirl injector and spray character. The aim was to explain the performance of heavy fuel oil pressure injector and provide spray character. They found parameter properties relation depend on half-angle, break angle length, mean droplet diameter and liquid viscosity on the pressure injector to expressed the inverse relation and droplet fuel compared pressure atomizer.

They concluded heavy fuel oil (mazut) pressure swirl injector was designed and fabricated examined high viscosity to water and another parameter [41].

Bonefačić et al., (2017) they studied combustion fuel oil spray by measuring data in cylindrical industry furnace. Numerical and simulation using commercial computational fluid dynamics software fluent modeling transport and reaction process in the furnace.
The aim was to improve combustion fuel oil spray and performance of the industrial furnace. They recognized an improved model of industrial furnace based on fuel and burner parameters of air-fuel ratio, fuel droplet diameter, fuel spray half-angle and burner swirl with 0.9-1.05,1.2 mm,300 67.5 respectively. Mixing fuel and air proportion is not suitable to increase unburned specific fractions. They concluded combustion heavy fuel oil spray quality, composition effect on a burner and fuel parameter of heating output decrease because of the shorter flame region [42].

ElSoad & Khalil (2015) they investigated combustion heavy fuel oil character the furnace and inside of a kiln to calcanei limestone in Egypt cement factory. The aim was to improve combustion heavy fuel oil inside the calciner of kiln and reduction of carbon dioxide and air pollution. Using ANSYS software fluent for Numerical and simulation. it was found that the HFO viscosity value assumption has a significant effect on the injection velocity and must be considered as a function of temperature during the analysis as this will significantly affect the combustion characteristics. Show the result of this researcher excess air ratio increase the combustion of HFO decrease. Generally, the turbulent model explains using Navier's stock equation based on gas flow and dynamic model [44].

Kontoulis et al. (2013) this paper studied heavy fuel oil thermos physical property blending product of residue and need refinery of marine engines. CFD software using simulation involvement increases the performance of heavy fuel oil, calculate physical property heavy fuel oil accounted for different ignition fuel oil quality .they found heavy fuel oil thermos physical property results of density, kinematic viscosity, and weight continuity. They concluded heavy fuel oil thermos physical property describe at different temperature value analytical calculation of the non-reactive spray flow performance utilizing and compared experimental value [43].

Escalera and Villasenor (1998) investigated radiation of heavy fuel oil combustion a cylindrical refractory industrial furnace. Experimental design and experimental method and test the performance of the furnace. The aim was avoiding unnecessary mixing air and increase necessary air in the jet. They found the velocity of the churn number and increase the combustion efficacy depends on properly mixing air and fuel [43].

2.1.3 Kiln Performance Review

Engin & Ari (2005) this thesis studied energy audit in the cement industry particularly the apparatus rotary kiln theoretical analysis. Fulfillment aims of the paper like an accurate account of energy consumption, analysis consume energy in the cement industry and obtained opportunity energy conservation. Show the result of this researcher acquired Specific energy consumption 2.95% per ton to cement production in the rotary kiln but much heat loss in the factory occurs in kiln exhaust gas 19.5%, hot air from cooler 5.61% and a radiation and convection loss 15.11%. They are concluded, several quite distinguish designs have been needed which application to rise heat from the fire at the bottom kiln and burning the limestone to produce quicklime [51].

Saidur et al. (2011) studied the cement industry produced cement for different purposes using the rotary kiln. The aim of this research with mixing fuel and air with the different methods applied such as experimental and CFD using ANSNS fluent software for involving different purposes to evaluate the performance of kiln and investigate waste heat recovery. The result of this paper to estimate the present average of kiln efficiency level with an account, increase the production of quality, save energy to reduce more fuel usage[52].

Novia et al. (2013) studied rotary kiln was used for control waste heat recovery in the cement industry. The purpose of the paper determines heat loss from the kiln system and reduces energy consumption. This investigation result explains temperature distribution in the system and effect of significant low efficiency of the system 53 %, heat loss in the kiln exhaust 21.88 %, total inner cooler exhaust 9.62% and kiln surface loss in convective and radiation 13.54%.They are concluded based on numerical estimation the most fuel saved amounted 738Kg/day [53].

Gutiérre et.al (2013) investigated quicklime production in the lime industry using vertical shaft kiln. The purpose of the research was done to determine the core point of analysis energy and exergy consumption. However, the influences of fuel consumption in the irreversible process-taking place in a vertical shaft kiln. They concluded to improve energy and exergy efficiency in the quicklime factory kiln 10% saving energy efficiency [54].

George et al. (2010) investigation the lime production of the small factory with applied processed in raw material limestone. There are various using operation control method and pressure evaluate performance lime shaft kiln to show the result of the paper to improving fuel and usage raw material and decrease any loss in industry special in the kiln in quarrying limestone 25% lost, however, using performance lime kiln to reduction of the product cost thus and increase competitiveness. Generally, they concluded applied operation all method of the burning process reduces fuel and limestone consumption impacts of the process [20].

Atmaca & Yumrutaş (2014) investigated performance in bricks and anzast layer in turkey cement a factory using the numerical calculation to the achieved purpose of research. Collect actual data on the cement a factory to analysis the effective and efficient of the energy management .as result estimation show 12.5MW energy lost and 11. 3 % cost of their only lost and production of cement need 3755,45KJ/Kg clinker .anzast layer in alumina refractory brick proved 72.17% reduction in energy consumption and corresponding to saving 21.78MJper ton of clinker production. They concluded the analysis layer advantage of refractory brick and heat transfer out of the kiln and global warming reduction [17].

2.2 Conclusion from the Literature Review

The chapter works of literature were reviewed on the combustion of heavy fuel, kiln performance, energy modeling, and the following major conclusions were identified:

Cost et al. (1991) generally idea Combustion of heavy fuel oil furnace was studied through measuring data from laboratory furnace.

Elbaz et al. (2018) summarized the Combustion of heavy fuel oil formation and oxidation particle matter was studied through experimental from the industrial furnace.

Azimiet et al. (2018) concluded Evaporation heavy fuel oil droplet was studied through a fully transient model from the marine engine, industrial furnace, and another combustion system.

Wu et.al (2007) studied Combustion heavy fuel oil was studied through the regenerative system from industrial furnace.

Engin, & Ari (2005) summarized Kiln performance is analyzed by CFD and FDM.

Puranik, V. S. (2007) generally Energy modeling of a factory was carried out using statistical analysis like cumulative (CUSUM) and prediction of regression.

Afkhami et al. (2015) estimate energy consumption with energy management to increase the energy opportunity by using the CUSUM technique.

Siebert et al. (2015) studied energy efficiency in each industry using energy manager based on energy management.

Novia et al. (2013) studied rotary kiln was used for control dissipate heat recovery in the cement industry.

Atmaca, & Yumrutaş (2014) investigated the performance of kiln within the insulator of bricks and anzast layer using energy management to an attained result of identify the loss of kiln and reduce the loss of heat.

Gutiérre et.al (2013) investigated vertical shaft kiln to determine analysis energy and exergy consumption. Show the result of this paper Improve energy and exergy efficiency in the quicklime factory kiln 10% saving energy efficiency.

Table 2.1: Literature Summary

Author	Titel	Technique	Result of the study	Study gap
Saidur et al. (2011)	A review on kiln system modeling	experimental and CFD using	kiln efficiency	Not provide any suggestions Not detail investigated kiln efficiency
Engin & Ari (2005)	auditing and recovery for dry type cement rotary kiln systems	theoretical analysis	acquired Specific energy consumption identified loss of heat	Not using experimental Possible recommendation and suggestion idea are not put to eliminate heat loss
Afkhami et al., (2015)	Energy consumption assessment in a cement production plant.	Cumulative SUM of differences	increase the thermal and electrical energy	No software used Take a few sample
Giacone et al., (2008)	investigated energy management	statistical control process	improve on energy efficiency and reduced energy cos	not detail energy management
Puranik, (2007)	CUSUM quality control chart for monitoring energy use performance	(CUSUM) and linear regres	monitoring energy use performance to improve energy consumption	not Minitab software used only investigate electrical energy consumption

2.3 Research Gap

Depending upon the literature some limitations are visualized in different research works. Most of the paper in Ethiopia is limited on Energy management programs are not investigated in detail, the study only for few samples but in this case a four-year data is collected and analyzed, they only deal with electrical energy consumption, Did not predict the future demand for energy consumption in ZCSC, Minitab software is not used, the various researcher investigated only focused on individual topics like combustion of heavy fuel oil, kiln performance, and energy analysis.

In addition, energy analysis mostly focused on the investigation of energy utilization performance and the development of energy management modeling programs. But if the factory has inadequate energy management, the process of quicklime production is not profitable. Therefore, this work-study through 4 years collected & analyzed sample data, different types of energy loss, main sources of loss & consumption, their influences on the energy performance and required products will be identified.

CHAPTER THREE

METHODOLOGY AND MARTIALS OF THE STUDY

3.1 Research Methodology

In this section, different tools or techniques were applied to perform this study are discussed. It includes data collection in logbooks and gash board table, literature review, experimental test by the thermal conductive detector (TCD), analytical balances, various statistical energy consumption, and management tools specially CUSUM and control chart.

To achieve the general and specific objectives of the thesis the following methodologies were adopted.

i. Study the quicklime production system and its energy performance (conduct preliminary walk-through energy audit inspection)
ii. Collect data on heavy fuel oil (Mazut) or both thermal and electric energy consumption (together with the energy bill) and the total quantity of quicklime produced by the factory for the last four years.
iii. Plot the energy consumed versus the quantity of quicklime produced for the last four years and study the pattern.
iv. Develop a least square regression model that best fits the energy consumption with the total production of quicklime.
v. Identify baseline energy consumption patterns (the one with consistent quicklime production) to develop an energy management program
vi. Conduct CUSUM analysis and develop energy M T&R.
vii. Development of energy modeling for the factory that is used for predicting its future energy demand.
viii. Study in detail the combustion performance of the Mazut furnace using data collected from the control panel of the quicklime production system
ix. Determine the electric and thermal energy consumption in producing a unit mass of quick lime
x. Provide suggestions to ZCSSC & Write the thesis report.

3.1.1 Data Analysis, and Interpretation

Different data such as electric, heavy fuel oil, electricity consumption, and energy bills for the last four years were collected directly collected from the factory logbook, interviewing the factory personnel, measuring, experimental test and inspection of the factory Facilities.

The collected data were analyzed using Microsoft Excel and Minitab 14 software through the helping of a statistical tool like CUSUM and regression analysis. After getting, the relevant data other related activities done using the analysis techniques and specified software.

- Calculating required collected data statistics.
- Validate the critical assumptions using CUSUM charts and graphs.

3.2 Sampling Technique

To obtain easy and simple work in measuring study proper preparation of sampling method before collect and analysis data is important. The scientific samples are taken from previous and current production processes under standard production condition i.e. three samples are taken for four years in the factory. During scientific sampling, the parts with considered characteristics are taken as much as possible in direct sequence.

3.2.1 Measurement Method and Materials

In experimental study work, different measurements are applied to measure precisely the required parameters in effectively and scientifically to get a relatively accurate result. The instrument used for this study is provided from the sample tested at Addis Abeba University College of Natural Sciences Chemistry laboratory using EA1112Flash CHNS/O-analyzer. The critical parameters of tested in this laboratory were the elemental analysis of furnace oil which is critically needed for the study energy consumption of ZCSSC. Different types of the instrument such as the measuring instruments are pyrometer, a measure of density heavy fuel oil and analyzer were used to measure and read the parameters needed to evaluate the energy utilization and these were also analyzed using excel & Minitab software 14.

3.2.2 Energy Conservation Opportunities

Energy audit is the critical needs in any country in the world. it is used to an Energy conservation, process modification improved measuring instrument, reduce electrical energy loss, reduction of fuel consumption, fuel economic maximizing behavior energy conservation opportunity is one of the primary ways to improve energy performance. We will focus on energy conservation opportunities and other ways to reduce energy consumption in the industry and the performance of the energy industry. Its identification methodology based on measured and modeled data for the lime industry.

3.2.3 Economic Analysis of the Proposed Energy-Saving Opportunity

Energy-saving provides technical solution options and economics analysis for the factory management to decide project implementation or priority. Moreover, energy cost contributes significantly. The economic analysis proposed a system based on the energy-saving opportunity that will be focused on fuel-saving, electricity-saving, improvement in product quality increase production and reduction in raw material consumption and reduction of other losses. Reduction of other loss means the surface heat loss from kiln, furnace and other equipment.

CHAPTER FOUR

INVESTIGATION ON COMBUSTION OF HEAVY FUEL OIL AND KILN PERFORMANCES

4.1Investigation of Thermal Performance of limekiln Plant

Limekiln is a rotary combustion kiln where heat transfers from combustion gas to calcium carbonate particles occurs. In quicklime production at ZCSSC, the limestone pebble is gradually heated in the kiln of 42 m length 2-3.5 m diameter, 1.3 rpm rotational speed until it reaches a temperature of about 900℃. Quicklime is said to be burning because it involves considering limestone pebble in high temperatures in a limekiln. The function of the limekiln is to convert limestone pebble for use in the calcination process. The term calcination refers to the process of thermal decomposition of the $CaCO_3$ to quicklime (C_aO) as shown by the reaction:

$$C_aCO_3 + \text{heat} \rightarrow C_aO + CO_2 \quad + \Delta \text{ H} \tag{4.1}$$

Limestone is fed to the kiln from cold end and the kiln slopes slightly 2.5° within slowly moving through the bottom towards the firing end as a result of inclination and rotation. Flue gases pass through electrostatic precipitator and lime dust captured in the precipitator are fed back to the kiln.

All basic processes steps occurring in the rotary kiln:

- Drying and preheating zone of the kiln is heated to 90-110℃, to evaporate all moisture. After this, the temperature increases to about 400℃ to liberate more determinedly bound water off [7].
- Calcining zone, the calcium carbonate is thermally decomposed in a range of temperature 400-900℃ to form calcium oxide, accompanied by the liberation of carbon dioxide.
- The kiln internal cooling, quicklime is cool down with air to 900-200 °C and is transport to intermediate storage.

4.1.1 Theoretical Analysis of Kiln

The performance of the kiln will be estimated with the energy analysis methods. The mass and energy analysis of the kiln by assuming the horizontal rotary kiln is an open system and under steady-state conditions of the kinetic and potential energy of the limestone and gas flows are negligible compared with their enthalpy; for evaluation.

The conversion degree of the reaction (a portion of limestone that dissociates), can be calculated as a function of the percentage of C_aO (A_{QL}) in quicklime and $CaCO_3$ in limestone pebbles [8]. The stoichiometry of the dissociation reaction of the limestone which was found from by a laboratory experimental test by taking samples of limestone pebble and production quicklime the percentage of $CaCO_3$ & C_aO in the quicklime is obtained value 93 and 84 % respectively. Other input required valve is the raw material of limestone pebble the factory using 1.354kg/sec (4.87 ton/hour) in Appendix E.

$$X= \frac{A_{QL}}{B\times(0.44A_{QL}-0.56)} \tag{4.2}$$

$$m_{Ql} = m_{Ls} \times B \times(1\text{-}0.44X) \tag{4.3}$$

where: X: fraction of limestone that dissociates

B: percentage of C_aCO_3 in the limestone

A_{QL} : Percentage of C_aO in the quicklime

m_{Ls}: Stand for the input of mass of limestone into preheating flows

Substituting percentage of C_aO in the quicklime and C_aCO_3 in the limestone pebble in the above equation (4.2), that result of the fraction of limestone that dissociates is 0.0025 and the mass of product quicklime is 1.339kg/sec.

The energy of flow, according to the first principle of thermodynamics equals [9].

$$E_{Ql} = m_{Ql} \times cp_{Ql} \times (T_{Ql} - T_a) \tag{4.4}$$

where: E_{Ql}: Quicklime production Energy

CP_{Ql} :The specific heat of the limestone valve depends on the temperature of the quicklime at 900°C the below equation (4.15) is 1.89kJ/kg K. Substituting the above data in equation (4.4), and then the energy output of the kiln in Quicklime production Energy production(E_{Ql}) is 2214.37 kJ/kg sec.

The Heavy Fuel oil furnace used in the factory is 280 liters per hour.

The heat input is 280 liters per hour. The specific gravity of fuel is used to convert this into kg/sec. Therefore: 280 liter / hour × 0.92kg/hour = 257.6kg/hr = 0.072kg/sec.

In the lime factory, analytical the classic expression to calculate the thermal efficiency of limekilns is used [14].

$$\eta_{lk} = \frac{E_{Ql} \times A_{QL}}{M_F \times LHV} \times 100\ \% \qquad (4.5)$$

Where: E_{Ql} : The energy output (kJ/sec)

A_{QL}: Percentage of C_aO in the quicklime

$\overline{m_F}$:Mass of flow rate of heavy fuel oil (kg/sec)

LHV:Lower heating valve (kJ/kg)

m_{fuel} : Mass of heavy fuel oil in kg/hr

Substituting the energy output, percentage of C_aO in the quicklime, the mass of flow rate of heavy fuel oil and lower heating valve above data in equation (4.5), Investigation Thermal Performance of limekiln Plant the energy efficiency is 63.01%.

4.2 Investigation on Combustion of Heavy Fuel Oil

Combustion takes place in a more rapidly chemical reaction at high temperature between fuel components and an oxidizing agent that release heat and light. The fuel mostly contains sources of compounds of hydrogen, carbon and in small contents of another element.

The combustion process is an exothermic chemical reaction release energy through light or heat. Therefore, it is a source of energy for most industries, businesses, homes, and transportations. The energy to be released during combustion depends on higher and/or lower heating valves. Combustion performance study is important not only to estimate the amount utilization of sources of energy but also it is important to analyze many industrial combustion processes to burn fossil fuel and determine such factors as energy losses and combustion efficiency.

Combustion efficiency is also important to study the emission characteristics gases such as the absence of carbon monoxide, nitrous oxide due to incomplete or high-temperature combustion.

4.2.1 Heavy Fuel Oil Composition and Ultimate Analysis

Heavy fuel oil composition parameters on standard molecular weight are required for analysis of the combustion reaction, which was found from by a laboratory experimental test by taking samples of heavy fuel oil burned on Zeway Caustic Soda Share Company.

To perform the combustion reaction easily during the burning of heavy fuel oil with atmospheric air, it is quite essential to standardize a mass fraction of the major air composition to handle the mass balance of the components relative to oxygen.

In the elemental analysis, the individual elements such as carbon, hydrogen nitrogen, sulfur, etc. present in the fuel are determined on a mass basis thus gives a relative amount of chemical element constituting heavy fuel oil. The sample tested at Addis Abeba University College of natural sciences chemistry laboratory using EA1112Flash CHNS/O-analyzer.

4.2.2 Test Procedure

The sample is then combusted furnace of temperature 900℃ and an oven temperature of 75℃ with an oxygen flow rate of 250 ml/min. The combustion products and N_2 are transported by a carrier gas (inert gas i.e helium) with carried gas flow rate of 120 ml/min, reference flow rate 100 ml/min, through the chromatographic column, in which chromatographic column, in which chromatographic separation takes place. After separation, the gas is sent to the thermal conductive detector (TCD).

The gas will pass TCD containing heated filament with applied current. These results change in current and electrical signals will be sent and electrical signals will be processed by installed Eager 300 software to provide the weight percentage of nitrogen, carbon, hydrogen, and sulfur contained in the sample run in duplicated and the average valves were taken.

4.2.3 Result Summary

In Table 4-1 given elemental analysis composition of heavy fuel oil from literature for comparison purpose and actual sample tested which taken from Zeway Caustic Soda Share Company is given. The result shows absent oxygen however, oxygen gets from 100% minus the total number of ultimate analyses. The result of the Heavy fuel oil certificate is available in the Appendix. Calibration points for every component. The sample was run in duplicate and the average values are to be taken Appendix D.

Table 4.1: Ultimate Analysis of Heavy Fuel Oil

Name	Sample code	N (%)	C (%)	H (%)	S (%)	O_2 (%)
Test 1	Oil	2.884	84.904	2.104	1.561	
Test 2	Oil	2.208	88.756	1.865	0.987	
Average	Oil	2.546	86.83	1.985	1.274	1.085

4.3 Proximate Analysis

The initial phase of the testing is sample preparation. During sample 39.ml of the sample is taken the proximate analysis of heavy fuel oil moisture and ash is 90.38 and 6.28% respectively in appendix D.

4.4 Analysis of furnace oil combustion

Heavy fuel oil (furnace oil) combustion analysis can be achieved to find the amount of energy released during furnace oil combustion. Mass and energy analysis of furnace oil, combustion air, and combustion products are very important.

4.4.1 Analysis of the Constituents of Combustion Air

The atmospheric air used for combustion is composed of 20.9% O_2 and 79.1% N_2 & inert on a dry basis. The standard atmospheric conditions of the location were: Pa =1atm, T_O = 25℃.
The average relative humidity of the air used for combustion is Ø= 53.25% [10].

$$\gamma_A = 0.622\frac{P_v}{P_o} \tag{4.6}$$

$$P_o = Pa - P_v \tag{4.7}$$

But the value of the partial pressure of the water,

$P_v = \emptyset P_{sat\ @25℃}$ =53.25% $P_{sat\ @25℃}$ from the steam table at 25℃ the value of the saturation pressure.

$P_{sat\ @25℃}$ = 3.17 kpa hence $P_v = 53.25\% \times 3.17\text{kpa} = 1.031\text{kPa}$ and

$P_o = (101.325 - 1.031)\text{kPa} = 100.3\text{kPa}$

Therefore, the humidity factor:

$$\gamma_A = 0.622\,\frac{P_v}{P_o} = 0.622\times\frac{1.031\text{kpa}}{100.3\text{kpa}} = 0.0064\,\frac{\text{kg of water}}{\text{kg of dry air}}$$

Where: Pa: atmospheric pressure

T_O: Atmosphere, inlet temperature

γ_A: Humidity Factor

P_o: Barometric pressure

P_v: Partial pressure of the water

P_{sat}: Saturation pressure

4.4.2 Theoretical Air-Fuel Ratio (TA)

The theoretical and actual air-fuel ratio of heavy fuel oil (Mazut) burning on a mass basis is important to determine the flow rate of flue gases. The flame temperature is an important factor to estimate heat transfer in a furnace and varies according to the air-fuel ratio. In this work, it is a measuring instrument of pyrometer to obtain the production of Quicklime temperature ranges between 800−900 ℃ at ZCSSC.

The chemical and physical properties of heavy fuel oil required for studying the stoichiometric combustion analysis of the actual air-fuel ratio compared to the literature review ratio is 13.42[11].

The standard chemical reaction of heavy fuel oil burning is the oxidation of 1kmol of wab completely into carbon dioxide and water vapor with inert nitrogen in the ultimate analysis (by mass) indicated in Table 4.1 using dry air, which is given by

$$7.24C+0.99H_2+0.034O_2+0.09N_2+0.04S+a_{th}(O_2+3.76\,N_2)$$
$$\rightarrow aCO_2+bH_2O+cSO_2+dN_2 \tag{4.8}$$

Balancing the coefficients of reactants and products yield

$$7.24C+0.99H_2+0.034O_2+0.09N_2+0.04S+7.74(O_2+3.76N_2)+7.24CO_2\rightarrow 0.9H_2O+0.04SO_2+29.2N$$

The theoretical air-fuel ratio on a mass basis $\frac{m_{air}}{m_{fuel}}$ can be obtained from equation (4.9)

$$TAFR=\frac{m_{air}}{m_{fuel}}=\frac{7.74kmole\times4.76\times29kg/mole}{100kg}=10.68kg\frac{air}{kg}\text{ of fuel} \tag{4.9}$$

4.4.3 Excess Air Supplied

The combustion efficiency of the furnace is low due to the large percentage of excess air is known to the combustion chamber. The excess air supplied to the furnace may be computed using the Percentage O_2 measured in the flue gas = 12 % for the kiln, from Appendix E, Table and substitute in (4.10) the excess air [12].

$$\text{EA} = \frac{O_2\%}{21\%-O_2\%} \times 100\ \% = \frac{12\%}{21\%-12\%} \times 100\% = 133.3\% \qquad (4.10)$$

4.4.4 Actual Air-fuel Ratio

From the definition of excess air, the actual air-fuel ratio is given by :

$$\text{AAFR} = \text{TAFR}(1 + \text{EA}) \qquad (4.11)$$

Substituting the above data in equation (4.11), and then the actual air-fuel ratio in production will be:

$AAFR = \left[1 + \frac{133.3}{100}\right] \times 10.68 = 25\ kg$ of air/kg of fuel.

4.4.5 Actual Combustion Reaction

The actual chemical reaction of heavy fuel oil is the burning of 1kmol of wab using wet air by

$$xC + yH_2 + zO_2 + wN_2 + eS_2 + a_{th}(O_2 + 3.76\,N_2)$$
$$\rightarrow aCO_2 + bH_2O + cSO_2 + dN_2 + eO_2 \qquad (4.12)$$

Equation (4.12) contains one unknown coefficient in the reactant side (a_{th}) and five unknowns on the product side.) Considering carbon mono oxide is neglect in the product because of less excess air of the fuel. These unknown coefficients can be readily determined using the definition of actual air/ ratio

Carbon balance: a=7.24

Hydrogen balance: b = 0.993

Sulfur balance: c = 0.04

The excess air of the product (e) (133-100) % = 0.33

These unknown coefficients can be readily determined using the definition of actual air/ ratio:

$$0.23 + a_{th} = a + \frac{b}{2} + c + e$$

$$a_{th} = 8.07$$

Nitrogen balance: $f = 3.76a_{th} + 0.091$

Define a new variable of the product, to be the sum of the stoichiometric coefficients of the dry gases in the products of burning of the actual chemical reaction excluding water vapor and equating it with coefficients, and results of reaction, of CO_2, H_2O, SO_2 and N_2 results of reaction ultimate analysis divided by molecular weight of each element are 7.24 ,0.995, 0.04and 30.43 with respectively.

$7.24C+0.995H_2+0.034O_2+0.091N_2+0.04S+8.07(O_2+3.76N_2) \rightarrow 7.24CO_2+0.99H_2O+0.04+0.33O_2+30.43N_2$

The air-fuel ratio is evaluated by taking the ratio of the mass of air (M_{air}) to the mass of fuel (M_{fuel}).Therefore actual air-fuel ratio (AAFR) on the basis for incomplete reaction approaching literature review is:

$$AAFR = \frac{M_{air}}{M_{fuel}} = \frac{8.07\text{kmole}\times4.76\times29\text{kg/mole}}{100\text{kg}} = 11.13 \text{ kg air/kg fuel}$$

4.4.6 Mass Flow Rate Analysis of Dry Flue Gases

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

Table 4.2: Molecular Weights of Fuel Constituents

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

The combustible elements in furnace oil are carbon, hydrogen, nitrogen, and sulfur. During the burning of furnace oil with dry air, these elements give carbon dioxide, water, and sulfur dioxide with inert nitrogen in the product. This reaction is given by equation (4.13):

Mathematically (for each constituent elements of fuel)

$$1\text{kg of heavy fuel oil} + \text{Dry air} \rightarrow CO_2 + H_2O + SO_2 + N_2 \quad (4.13)$$

Mathematically:

$$C + O_2 \rightarrow CO_2$$

$$H_2 + ½\, O_2 \rightarrow H_2O$$

$$S + O_2 \rightarrow SO_2$$

Constituents of fuel

$$C + O_2 \rightarrow CO_2$$

$$12 + 32 \rightarrow 44$$

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

$0.87C + 0.87 \times 2.67O_2 \rightarrow 3.2\ CO_2$

4 kg of hydrogen requires 32 kg of O_2 to form 36 kg of water therefore 1 kg of hydrogen requires 32/4 kg i.e.8 kg of O_2

$0.02\ H_2 + 0.02 \times 8\ O_2 \rightarrow 0.182H_2O$

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

$0.013 + 0.013 \times 1O_2 \rightarrow 0.026SO_2$

$$\text{Excess air} = \text{Actual air supplied} - \text{Theoretical air required} \tag{4.14}$$

EA= 25 kg - 11.13 kg= 13.87 kg of air.

Excess O_2 = 13.87 kg x 0.23(by mass) = 3.2kg

Excess N_2=13.87kg×0.77 (by mass) = 10.68kg

The final constitutes of flue gas with 11.87 kg (133.33%) of excess air for every 1 kg fuel is the summation of;

$CO_2 =$ 3.2 kg air/kg of fuel

$H_2O = 0.182$ kg air/ kg of fuel

$SO_2 = 0.026$ kg/kg of fuel

O_2 = 3.2 kg air/kg of fuel

N_2 = (10.68kg/kg of fuel+ 10.43kg/kg of fuel) = 21.11kg/kg of fuel

Therefore, total mass of flue gas (m_{fg}) = 27.72 kg flue/ kg fuel

Multiplying total mass of flue gas with mass flow rate of furnace oil with retention time gives the mass flow rate of flue gases therefore: mass of flue gas.

$\dot{m}_{fg} = 27.72\frac{\text{kg flue}}{\text{kg fuel}} \times 0.072\text{kg/sec} = 1.98\text{kg flue/sec}$

4.4.7 Measured Combustion Temperature of the Furnace

The combustion temperature of the furnace is important in the analysis of the energy loss due to Dry flue gases. Due to the absence of a furnace temperature sensing instrument of pyrometer in the kiln but this temperature is not corrected reading some problem in the analysis But, the combustion temperature usual in the furnace could be readily estimated from the moisture content and excess air used during combustion [12]. For 90.8% moisture content of heavy fuel oil, the furnace temperature at 133.3% excess air is 900℃.

4.4.8 Specific Heat of Dry Flue Gases

For heavy fuel oil, the specific heat of dry flue gas is given [12].

$$C_{P_{fg}} = (0.3+0.000038T_{fur})\ \text{kcal/kg℃} \quad (4.15)$$

Where: T_{fur} = Furnace temperature =400℃

$C_{P_{fg}}$ = specific heat of dry flue gas

Substituting the value of furnace temperature in the equation (4.15) specific heat of the flue gas is 1.32kJ/kg ℃).

4.4.9 Heating Value of Heavy Fuel Oil (Mazut)

The calorific value of heavy fuel oil used in zeway caustic soda Share Company is important to evaluate the energy input to the furnace. The higher heating value of heavy fuel oil (HHV) is dependent on the physical composition, whereas the lower heating value (LHV) of furnace oil depends on the physical as well as chemical composition. The chemical and physical composition heavy fuel oil are shown Table 4.1

The temperature of the exhaust gases is calculated through the energy balance of the preheating zone [13].

Mass of water = number of mole water × molecular weight of water

$m_{H2O}=N_{H2O} \times M_{H20}$=0.993 kmole ×18kg/mole =17.874kg

$$LHV=GCV-(M_{water})h_{fg} \quad (4.16)$$

Where: h_{fg} : Enthalpy of vaporization of water = 2441.7kg/kJ (Saturated water-Temperature table)

H: mass of percent of hydrogen

M_{H20}: Mass of water vapor in the flue gas

M_{H20}= 9 H (1- %M) + % M (Combustion Analysis Basics) (4.17)

From Table 4.1 and 4.2 the percent of hydrogen in heavy fuel oil 1.985 %. Hence Equation (4.17)

M_{H_2O}= 9× 1.985(1-0.9) + 0.9 = 0.92

At the standard reference state of with 1atm for the calculation of heating values. Based on thermodynamics table 4.1 and higher heating valve in the petroleum organization substituting the values in the Equation (4.16), HHV,h_{fg} and LHV is 40789.85kJ/kg.

4.4.10 Estimated of Heavy Fuel Oil Mass Flow Rate

The heavy fuel furnace used in the factory is 280 liters per hour.

The heat input is 280 liters per hour. The specific gravity of fuel is used to convert this into kg.

280 liter / hour $\times$ 0.92kg/hour $=$ 257.6kg/hr $=$ 0.072kg/sec.

4.5 Energy Analysis

Thermal energy analysis on the Combustion of Heavy Fuel Oil must be conducted to know the thermal and combustion efficiency of a furnace. The analysis is done based on the energy inputs and outputs of the furnace. All inputs and outputs of the energy are shown in figure (4.2).

4.5.1 Determination of Input Energies

Thermal energy analysis of furnace must be conduct to know the thermal and combustion efficiency of the furnace. The analysis is done based on the energy inputs and outputs of the furnace as illustrated in figure 4.1, heat due to pre-heating of furnace oil and combustion air is the input energies. Furnace Fuel Oil Energy contains chemical energy and heat energy by the feature of its chemical constituents and pre-heating of the fuel at the inlet to the furnace respectively.

4.5.1.1 Chemical Energy of furnace oil

The chemical energy of the furnace oil is quantified using its heating value. To calculate the energy efficiency of the furnace on GCV, the chemical energy of the furnace oil must be found. The chemical energy of the furnace oil is obtained by multiplying the GCV of the fuel with the mass flow rate of the fuel.

$$Q_f = m_{fuel} \times GCV \tag{4.18}$$

Where: Q_f:Chemical energy of the fuel

m_f :Mass flow rate of the fuel =0.072kg/sec

LHV : Lower heating value of the fuel = 40789.85kJ/kg

Substituting the above data in equation (4.18), then the chemical energy of the fuel will be:

$Q_f = m_f \times GCV = 0.072kg/sec \times 43031kJ/kg = 3098.23$ kW

4.5.1.2 Energy due to Pre-heating

The energy due to fuel pre-heating is the enthalpy of furnace oil by advantage of its temperature elevation relative to the atmospheric temperature. The enthalpy of furnace oil due to its pre-heating from the ambient temperature to pre-heating temperature can be obtained using the following thermodynamic path. The energy due to pre-heating temperature can be obtained using the following equation (4.19)

$$Q_{pfl} = m_f\, c_{pf}\, (T_{pf} - T_{amb}) \tag{4.19}$$

Where: Q_{pfl}: Energy content due to fuel pre-heating Specific heat of fuel

m_{fuel}:Mass flow rate of the fuel =0.072kg/sec

c_{pf}:Specific heat of fuel=1.27 kJ/kg°C

T_{pf}:Fuel pre-heating temperature =110°C

T_{amb}:Ambient temperature =25°C

Substituting the above data in equation (4.19), then the Energy due to Pre-heating is 7.78kW

4.6 Energy of Combustion Air

The inlet air temperature is at ambient temperature. Since the enthalpy of the flue gas is calculated relative to the temperature of the entering air, the relative enthalpy of combustion air is zero. The actually balanced reaction equation is known, the mole coefficients may then be used to write an equation for the enthalpy of the products per unit mass of Heavy fuel oil. Because all the reactants are assumed elements at the reference temperature, the enthalpy of the reactants is zero. Q_a = 0kJ/kg

4.6.1 Determination of the Output Energies

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

- Heat Loss due to Sensible Heat of the Dry Flue Gas
- Loss due to the presence of H_2 in fuel (loss due to latent heat)
- Heat loss calculation of the rotary kiln
- Loss due to the moisture content of the air, &Loss due to the moisture content of the fuel

4.6.1.1 Heat Loss due to Sensible Heat of the Dry Flue Gas

The energy loss due to dry flue gas leaving the kiln can be obtained using the mass flow rate of dry flue gas and enthalpy change of dry flue gas at flue gas temperature relative to the ambient temperature of flue gas. The analysis is executed using [15].

$$Q_{fl} = m_{flue} c_{pf}(T_{flue} - T_{amb}) \tag{4.20}$$

Where: Q_{fl}: Heat loss due to sensible heat of the dry flue gas

m_f : Mass flow rate of fuel =0.072kg/sec

c_{pfl} : Specific heat capacity of flue gas=1.4 kJ/kg℃

T_{fl}: Fuel Gas temperature =400℃

T_{amb}: Ambient temperature =25℃

But, m_{flue} is determined multiplying the mass of dry flue gas (m_{fl}) by the mass flow rate of the fuel, and also

m_{fuel}=Mass of dry flue gas = mass of CO_2 + mass of H_2O +mass of SO_2+mass of O_2+mass of S_2O +mass of N_2

m_{fl} = 3.2 kg/kg of fuel + 0.182Kg/kg of fuel + 0.026kg/kg of fuel + 3.2kg/kg of fuel + 21.11kg/kg of fuel

m_{fl} = 27.72 kg (dry flue gas) /kg of fuel

Therefore:

$$\dot{m}_{fl=} m_{fl} \times \dot{m}_f \tag{4.21}$$

$$\dot{m}_{fl=} m_{fl} \times \dot{m}_f = 27.72 \ \frac{\text{kg flue}}{\text{kg fuel}} \times 0.072\text{kg/sec} = 1.98\text{kg flue/sec}$$

Substitute the above data in equation (4.21) and energy loss due to sensible heat of the dry flue gas is 978.17kW.

4.6.1.2 Heat Loss due to the Presence of H_2 in Fuel

During the combustion process of the furnace oil, the hydrogen contained in it reacts with oxygen and water will be formed. The water formed takes away some of the energy released during the combustion process. This energy loss due to the presence of hydrogen in the furnace oil can be calculated (4.22).

$$Q_{H_2} = M_{H_2O} \times m_f[h_{fg@25℃} + c_{pf} (T_{flue} - T_{amb}) \tag{4.22}$$

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

m_{fuel} :Mass flow rate of fuel =0.072kg/sec

c_p : Specific heat capacity =1.89 kJ/kgk

T_{flue}: Flue Gas temperature =400℃

T_{amb}: Ambient temperature =25℃

$h_{fg@25℃}$: Enthalpy of water=2441.12 kJ/kg

$M_{H_2}O$: Mass of water per kg of fuel =0.92Kg/kg of fuel

Substitute in the above data in equation (4.22) and energy loss due to the Presence of H_2 in Fuel is 196.5kW

4.6.1.3 Heat Loss due to Moisture Content of Air

The air used for combustion under standard conditions contains moisture. The energy loss due to the moisture content of the air is similar to the moisture content of the furnace oil described above. The energy loss due to moisture in the combustion air is given by [16].

$$Q_{ma} = AAS \times \gamma_A \times \dot{m}_{fule}(c_p(T_{flue} - T_{amb})) \qquad (4.23)$$

Where: Q_{ma} : Heat Loss due to Moisture Content of Air

AAS: Actual air supplied= 25 kg of air / kg of fuel

γ_A: Humidity Factor=0.0064kg of water/kg of air

m_f :Mass flow rate of fuel =0.072kg/sec

c_p : Specific heat capacity =1.4kJ/kgk

T_{fl}: Flue Gas temperature =400℃

T_{amb}: Ambient temperature =25℃

Substitute the above data in equation (4.23) and Heat Loss due to Moisture Content of is 6.048kW

4.6.1.4 Heat Loss due to Moisture Present in Fuel

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

$$Q_{MF} = M_{H_2O} \times \dot{m}_f \times [h_{fg@25℃} + c_{pf}(T_{fl} - T_{amb}) \qquad (4.24)$$

Where: Q_{mf} : Heat Loss due to the Presence in Fuel

$\dot{m}_f$:Mass flow rate of fuel =0.072kg/sec

c_p : Specific heat capacity =1.4 kJ/ kgk

T_{fl}:Flue Gas temperature =400℃

T_{amb}:Ambient temperature =25℃

$h_{fg@25°C}$:Enthalpy of water=2441.12 kJ/kg

M: Mass of water per kg of fuel =0.92Kg/kg of fuel

Substitute the above data in equation (4.24) and Heat Loss due to Moisture Present in Fuel is 192.2kW

4.6.1.5 Heat Loss Calculation of the Rotary Kiln

Due to the temperature difference between the inner surface and ambient air temperature, there will be heat transfer from the kiln to the environment. The heat transfer from the rotary kiln takes place due to conduction, convection, & radiation. This heat transfer is assumed to waste heat. Conservation of this heat will improve the thermal efficiency of the rotary kiln.

it is necessary to calculate Reynolds number (Re), Radiation heat transfer coefficient (h_{rad}), convective heat transfer coefficient (h), Nusselt number (Nu) and thermal resistance (R)[17].

The rotary kiln configuration, which is taken from the ability measured and manual, registered.in AutoCAD software in the figure (3.1) of the lime production process.

$$Q_{kiln\ loss} = \frac{T_{in} - T_{out}}{R_{total}} \tag{4.25}$$

Where: R_{total}:The total thermal resistance of the system and calculated from

T_{in}: Input temperature

T_{in} : Ouput temperature

$Q_{kiln\ loss}$:Heat loss calculation of the rotary kiln

Conduction, convection, and radiation thermal resistance values are determined from the expressed:

$$R_{total} = R_{Conv,1} + R_{cond,1} + R_{cond,2} + R_{cond,3} + \frac{R_{Conv,2} \times R_{rad}}{R_{Conv,2} + R_{rad}} \tag{4.26}$$

$$R_{cond,1} = \frac{1}{2\pi L_1 k_1} \ln \frac{r_3}{r4} \tag{4.27}$$

$$R_{Conv,2} = \frac{1}{2\pi L_1 r_1 h_2} \tag{4.28}$$

$$R_{Conv,1} = \frac{1}{2\pi L_1 r_4 h_1} \tag{4.29}$$

$$R_{cond,2} = \frac{1}{2\pi L_1 k_2} \ln \frac{r_2}{r_3} \tag{4.30}$$

$$R_{cond,3} = \frac{1}{2\pi L_1 k_3} \ln \frac{r_1}{r_2} \tag{4.31}$$

$$R_{rad} = \frac{1}{2\pi L_1 r_1 h_{rad}} \tag{4.32}$$

Table 4.3: The Features of the Air Temperature

Parameter	Pre-heating zone (1)	Calcination zone (2)	Burning zone (rad)
Temperature T	400 ℃	800℃	900℃-1000℃
Density ρ kg/m^3	0.5242	0.3287	0.321
Length of rotary kiln	14	9	19
Specific heat(kJ/kg.k)	1.068	1.156	1.172

Substitute the above data in equation (4.33, 4.34& 4.35) to acquired Dynamics viscosity (μ), thermal conductivity (k) and Prandtl number (Pr), are done and the result is presented in the above table 4.3

$$\mu = \left(\frac{1.458\times10^{-6} T_K{}^{1.5}}{T_K+110.4}\right) \tag{4.33}$$

$$k = \left(\frac{0.2646 T_K{}^{1.5}}{T_K+245.4\times10^{-12}/T_K}\right) \tag{4.34}$$

$$P_r = \left(\frac{cp\times\mu}{k}\right) \tag{4.35}$$

Table 4.4: The Result Parameter of the Factory Acquires the above Formula

Parameter	Pre-heating zone (1)	Calcination zone (2)	Burning zone (rad)
Thermal conductivity k, w/m.k	0.0516	0.0706	0.741
Thermal Diffusivity α,m^2/s	8.951×10^{-5}	1.85×10^{-4}	2.1×10^{4}
Dynamics viscosity μ ,kg/m.s	3.28×10^{-3}	4.37×10^{-3}	4.59×10^{-3}
Kinematic viscosity v, m^2/sec	6.253×10^{-5}	1.33×10^{-4}	1.529×10^{-4}
Prandtl number pr,	0.68	0.715	0.725

In reference to these assumptions, cross-sectional pictures of the modeled heat recovery exchanger are given in [17]. The temperature of the air between the surface of the rotary kiln and the heat exchanger is found out by taking the arithmetic average of the surface temperature of the rotary kiln and the outside atmosphere temperature. In order to find the coefficient of heat convection, the properties of the air should be defined from the rotary kiln temperature.

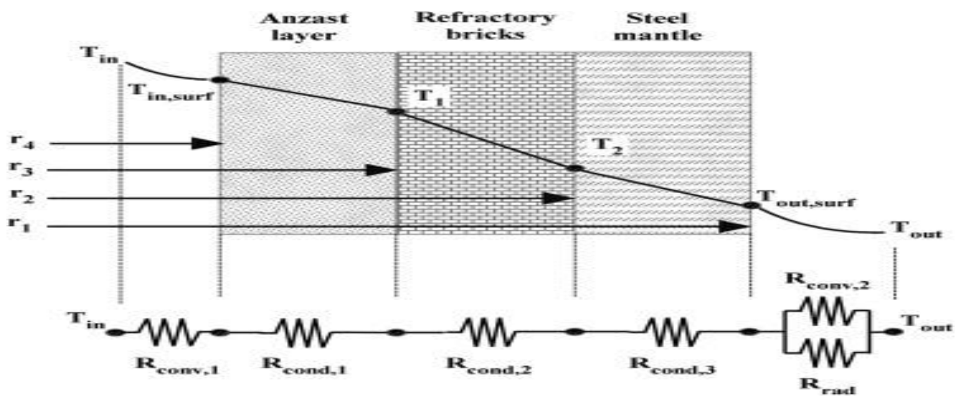

Figure 4.1: Thermal Resistance for Heat Transfer Through the Covering of the Kiln [17]

T_{in} is the inner temperature of the rotary kiln and $T_{surfaces}$ is the surface temperature of the layer of the kiln is 900°C & 70°C r_1, r_2, r_3 & r_4 are 1.8,1.82,1.84 and 1.86 respectively. The rotary kiln inner radiuses are $r_1 - r_4$ (1.8 m−2m). Give the thickness of the steel covering, $r_2 - r_3$(1.82m − 1.84m) is the thickness of the insulator .the rotary kiln speed is 1.3rpm, the slope of angle 2.5° and the thickness refractory is 0.02m, Velocity is1.3 m/sec, Internal diameter is1.8m, Outer diameter is 2m,and Thickness of refractory = 0.02m

$$h_{rad} = \varepsilon\sigma({T^2}_{out,surface} + T_{out})\,(T_{out,surface} + T_{out}) \tag{4.36}$$

$$Re = \frac{\rho \times V \times di}{\mu} \tag{4.37}$$

$$Nu = 0.023Re^{0.8}Pr^{0.4} \tag{4.38}$$

$$h = \left(\frac{Nu \times k}{D}\right) \tag{4.39}$$

Where: h: convection heat transfer coefficient

h_{rad}: Radiation heat transfer coefficient and its value are determined from different input data.

Re: Reynolds number

Nu: Nusselt number

ε: the emissivity of the surface = 0.78

σ: Stefan−Boltzman constant = $5.67\times 10^{-8} W/m^2k^4$

Several equations have been used to total heat transfer to the rotary kiln wall and charge in rotary kilns based convection heat transfer coefficient.

A. Pre-Heating Zone of the Rotary Kiln at ZCSSC

The preheating zone is the longest zone and lower gas temperatures as the name suggests this section is the preheating part of the kiln.

Limestone pebble pre-heater is used to easily heating the raw material before it enters the calcining or burning limekiln.it is before Enter the crusher 25℃ but discharge the quicklime in the kiln 900℃ to 90℃ reduced the temperature transfer to cold limestone pebble.

For their calculation, the formulas are given below**.**

Substitute the above data (Table 4. 1) in the pre-heating zone equation (4.27,4.29, 4.37, 4.38, and 4.39) parameter of property.

$$R_{cond,1} = \frac{1}{2\pi L_1 k_1} \ln\frac{r_3}{r4} = -0.023$$

$$R_{Conv,1} = \frac{1}{2\pi L_1 r_4 h_1} = 0.45$$

$$Re_1 = \frac{\rho\times V\times di}{\mu} = \frac{0.5243 kg/m^3\times 0.25 m/sec\times 1.8 m}{3.12\times 10^{-3} kg/m.s} = 75.62$$

$$Nu_1 = 0.023 Re^{0.8} Pr^{0.4} = 0.994$$

$$h_1 = \frac{Nu\times k}{D} = 0.016 w/mk$$

B. Calcining Zone of the Rotary Kiln at ZCSSC

The calcining zone is higher in temperature than pre-heating zones, it is commonly linked with higher alumina refractory materials. The calcining zone also is extended due to less energy transfer from the gas, causing the burning zone to move out at a rate of raw material 4874.4kg/hr. Since the gas is still being heated in the calcining zone, it continues to supply heat in the preheat zone. Substitute the above data in the calcining zone equation (4.27, 4.28, 4.37, 4.38, and 4.39) parameter of property.

$$R_{cond,2} = \frac{1}{2\pi L_1 k_1} \ln\frac{r_3}{r4} = -0.0775$$

$$R_{conv,2} = \frac{1}{2\pi L_1 r_4 h_1} = 0.025$$

$$Re_2 = \frac{\rho\times V\times di}{\mu} = \frac{0.5243 kg/m^3\times 0.25 m/5\times 1.8 m}{3.12\times 10^{-3} kg/m.s} = 145.43$$

$Nu_2 = 0.023Re^{0.8}Pr^{0.4} = 1.086$

$h_2 = \frac{Nu \times k}{D} = 0.221 w/mk$

C. Burning Zone of the Rotary Kiln at ZCSSC

The burning zone is used to change composition raw material temperature between the "free" lime in the calcined feed and alumina-silica materials is in the region of 900 ℃, that is why the burning section of the kiln is lined.

Limekiln is usually activated at from 900℃ to 1100℃ in the burning zone. Where temperatures above 1100° C are employed in the burning zone, the lime will be partially vitrified on the outside of the lumps due to the combination of the calcium oxide with impurities (SiO_2 and Al_2O_3 always present [18].

$R_{cond,3} = \frac{1}{2\pi L_1 k_3} \ln\frac{r_1}{r_2}$ = -0.000264K/W

Energy loss in the rotary kiln part pre-heating zone, calcination zone, and burning zone totally calculated depend on the parameter of the kiln.

Substitute the relevant data and constants are obtained from onsite measurements in calcining zone equation (4.36)

$h_{rad} = \varepsilon\sigma(T^2{}_{out,surface} + T_{out})\,(T_{out,surface} + T_{out}) = 0.78 \times 5.67 \times 10^{-8}(70^2 + 900^2)\,(70 + 900) = 35\ W/m^2\ K$

Where: R_{total}= total thermal resistance of the system and calculated from

$R_{total} = R_{Conv,1} + R_{cond,1} + R_{cond,2} + R_{cond,3} + \frac{R_{Conv,2} \times R_{rad}}{R_{Conv,2} + R_{rad}} \approx 0.4$

Heat flow from the rotary kiln towards the heat converter can be provided by convection and radiation. In this case, total heat in the system is equal to the sum of the heat loss caused by conduction, convection, and radiation. Results obtained from a case study can be given to explain energy analysis for the kiln. The results of the energy loss of rotary kiln analysis for the rotary kiln unit are presented below.

$Q_{kiln\ loss} = \frac{T_{in} - T_{out}}{R_{total}}$ = 2193W=2.193kW.

Table 4.5: Summary Of Input-Output Energy

No.	Input energy [kw]	No.	Output energy [kw]
1	Fuel due to its heat content = 3098.232Kw	1.	Heat loss due to dry flue gas = 978.1 kW
2	Energy due to Pre-heating = 7.78 kW	2.	Heat loss due to hydrogen in furnace fuel oil = 196.5 kW
3	Combustion air = 0 Kw	3.	Heat loss due to moisture in air = 6.048 kW
4	$\sum_{i=1}^{3} 3106.012$	4.	Heat loss due to moisture in fuel = 192.2kW
		5.	Heat loss of kiln = 2.193 kW
		6	$\sum_{i=1}^{5} 1375.041$

4.6.1.6 The Sankey Diagram

The Sankey diagram is a very useful tool to represent an entire input and output energy flow in any energy equipment or system such as kiln, furnace and preheat oil after carrying out energy balance calculations summarized in table 4.5 [26]. this diagram represents visually various outputs and losses so that energy managers can focus on finding improvements in an arranged manner. The following Sankey diagram is done.

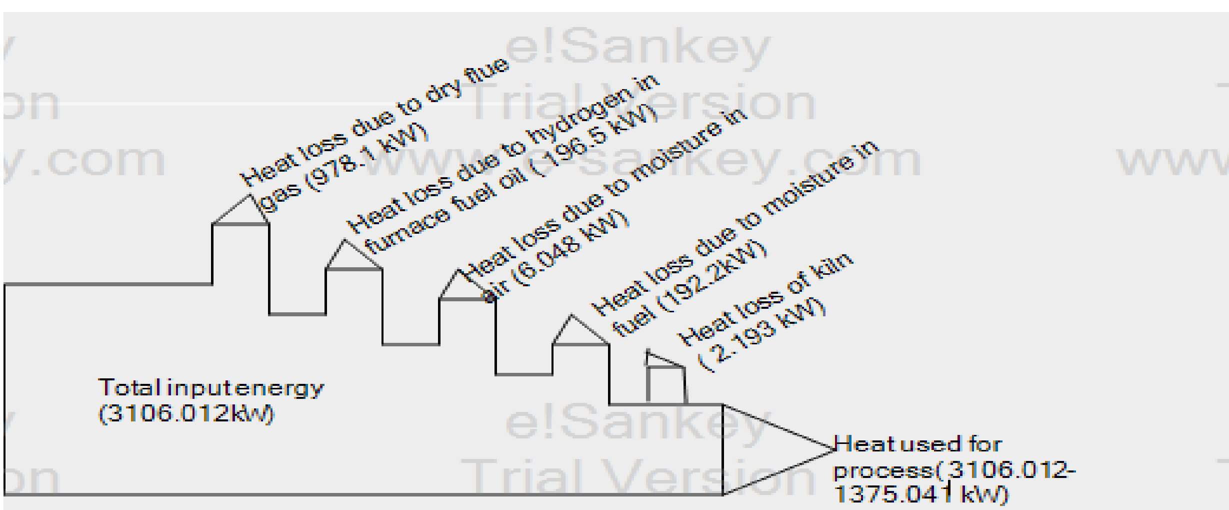

Figure 4.2: Energy Sankey Diagram of the Kiln

4.7 Efficiency of the Furnace Based on Input-Output Method

To find the amount of energy released during Heavy fuel oil combustion, the following mass, and energy analysis of the furnace oil, the combustion air, and the combustion products are very important. Since the composition of the gas products of the actual chemical reaction in the furnace, efficiency must be determined using the factory operating condition of the furnace and combustor.

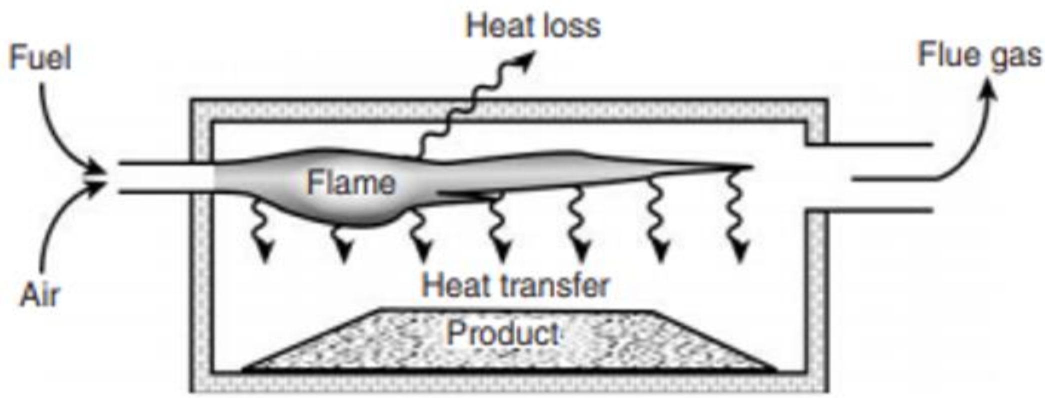

Figure 4.3: Lime Production Using the Type of Furnace Design [19]

Zeway caustic soda shares company combustion heavy fuel oil physical and chemical behavior indicated in table 4.1 burns to heat crushed limestone pebbles in the kiln. The flue gas leaves the kiln at 400℃ and enters at 900℃ the input energy to produce flue is the combustion of heavy fuel oil with atmosphere air.

The efficiency of a furnace can be determined by measuring the amount of heat absorbed by the standard and dividing this by the total amount of fuel consumed.

The Thermal efficiency of a furnace is defined as the percentage of heat input that is effectively utilized to generate a flame furnace [19].

The quantity of heat output (Q_O **)** that will be transferred to (flue gas) stock can be calculated within this equation (4.40)

$$Q_{\text{output}} = m_{Ql} \times cp_{Ql} \times (T_{Ql} - T_a) \quad (4.40)$$

Where: Q_{Ql}: Output heat (kJ/hr)

cp_{Ql}: Specific heat of billet = 1.89 kJ/kg

T_{Ql} : Temperature of quicklime = 900℃

T_{ph} : Temperature of limestone after preheating = 25℃

m_{output} :Mass of quicklime production = 1.039kg/sec

Substituting the above data in equation (4.16), then the chemical energy of the fuel will be:

Q_{output}: $m_{output} \times cp_{Ql} \times (T_{Ql} - T_a)$ = 1.033kg × 1.89kJ/kg(900℃ − 25℃) = 1703.38kJ/kg

The quantity of Heat input **(Q_i)** that will be transferred to supply can be calculated with this equation:

$$\eta_{overall} = \frac{\text{heat output}}{heat\ input} \times 100\% \qquad (4.41)$$

Substituting the energy output and mass of flow rate of heavy fuel oil sec and gross calorific value above data in equation (4.41).

Thermal efficiency of the furnace = $\frac{1703.38}{0.072 \times 40789.85} \times 100\%$ = 58%

4.8 Efficiency of the Furnace Based on heat loss method

In this method efficiency is the difference between the energy losses and the energy input. Similar to the method of evaluating boiler efficiency by the direct method, furnace efficiency can also be calculated by the heat loss method. Furnace efficiency is calculated after subtracting sensible heat loss in flue gas, loss due to moisture in flue gas, heat loss due to openings in furnace, heat loss through furnace coating and other unaccounted losses.

In order to find out furnace efficiency using the indirect method, various parameters that are required are hourly furnace oil consumption, material output, excess air quantity, the temperature of flue gas, temperature of the furnace at the various zone and hot combustion air temperature. The combustion efficiency of the furnace based on the heat loss method on GCV is given by [19].

$$\eta_{th} = \left(1 - \frac{\sum_{i=1}^{5} Energy\ Losses}{\sum_{i=1}^{3} Energy\ Input}\right) \times 100\% \qquad (4.42)$$

Substituting the values of the summations of energy losses and energy inputs from Table 4.8 and the thermal efficiency will be:

Thermal efficiency of the furnace $= \left(1 - \frac{\sum_{i=1}^{5} 1375.041}{\sum_{i=1}^{3} 3106.012}\right) \times 100\%$ = 55.8%

Thermal efficiency of furnace there is some difference in directed and directed method because cause of method and input of parameter.

4.8.1 General Comment of the Energy Performance of the furnace

The energy efficiency of the furnace of the factory is found to be 55.7%. This efficiency is less than the expected performance of a new furnace oil fired furnace, which is equal to 75% [4]. The main causes that contribute to the significant drop in efficiency of the furnace is the energy loss due to

- Hydrogen in furnace oil (14.29%)
- Moisture in combustion air (0.43%)
- Dry flue gas loss (71.1%)
- Moisture in fuel (13.75 %)
- Heat loss of kiln (0.15%)

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

4.9 Estimate of Improving Efficiency of Furnace

The efficiency of a furnace oil-fired furnace is 75 % on GCV [19]. From the energy analysis conducted above the efficiency of the furnace is 55.8 %. This implies that the factory furnace waste about 16.3 % of the energy input on gross calorific value. This waste show that attention to the details of the energy wastages causes must be investigated and measures must be taken to improve the energy efficiency of the furnace to save energy.

The main cause of energy losses in the furnace is energy loss due to the moisture content of combustion air, moisture and hydrogen content of furnace oil, kiln surface loss and excess energy loss due to dry flue gas. From the above-mentioned sources of energy losses in the furnace, the only controllable loss is energy loss due to dry flue gas. This energy loss can be minimized or controlled to an optimum level by controlling the excess air admitted into the furnace. For furnace oil-fired furnace the recommended percent excess air admitted to the furnace is 15% with the volume percent of CO_2 is also 15% [12]. But the average excess air supplied to the furnace of the factory furnace is 133.3% with the volume percent of CO_2 being

7.24%. The technical analysis of controlling excess air is executed for the recommended percentage i.e. 15% as follows. When the excess air percentage used for combustion is changed to 15%, types of energy loss in the furnace that is affected is energy loss due to dry flue gas. To find this energy loss at 15% of excess air and the corrected efficiency the theoretical air-fuel ratio, actual air supplied, mass flow rate of the flue gas and furnace temperature must be determined as is done in the estimation of energy.

4.9.1 Theoretical Air-Fuel Ratio (TAFR)

From Equation (4.9) the theoretical amounts of air required to burn the furnace oil at the given percent of the constituents of the furnace oil is 10.68 kg of air/kg of oil.

4.9.2 Actual Air - Fuel Ratio of Furnace oil (AAFR) at 15% Excess Air

Using Equation (4.44) the actual mass of air used during the burning of one kg of fuel in fired furnace can be easily found.

$$\text{AAFR} = [1+\frac{EA}{100}]\times \text{TAFR} \tag{4.44}$$

Where: EA: Excess air supplied = 15%

TA: Theoretical amount of air fuel ratio

Substituting the values of the theoretical amount of air and 15% of excess air in the actual mass of air supplied (4.44)to the combustion furnace is given by

$\text{AAFR} = [1+\frac{15}{100}]\times 10.68 = 12.282$

Excess Air Quantity (EAQ)

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

Excess air quantity = Actual air supplied - Theoretical air required

Excess air quantity = 12.282 – 10.68 =1.602 kg of air

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

In order to calculate the energy losses due to dry flue gases (stack loss), the mass flow rate of the flue gases must be calculated. To find the mass flow rate of the dry flue gases the composition of the gaseous products of the actual chemical reaction in the furnace must be determined first. The constituents of dry flue gases are $CO_2, SO_2, N_2, and\ O_2$.

The mass of each constituent of dry flue gas is given by equation (4.45).

$$m_{dry\ flue} = \text{mass of } CO_2 + \text{mass of } SO_2 + \text{mass of } N_2 + \text{mass of } O_2 \qquad (4.45)$$

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

$$\frac{0.87\times44}{12} + \frac{0.013\times64}{32} + 12.282\left(\frac{77}{100}\right) + 1.602\left(\frac{23}{100}\right) = 13.04 \text{ kg of dry flue gas/kg of fuel}$$

Therefore mass flow rate of dry flue gas is given by equation (4.46)

$$\dot{m}_{fl} = m_{fl} \times \dot{m}_f = 13.04\,\frac{\text{kg flue}}{\text{kg fuel}} \times 0.072\text{kg/sec} = 0.94\text{kg flue/sec}$$

4.9.4 Combustion Temperature of the Furnace & CP at 15% Excess Air

For 0.5% moisture content of furnace oil at 15% of excess air the furnace temperature is 722.6 ℃ [21]. The formula used for determine the mean specific heat is given by (4.46)

For heavy fuel oil, the specific heat of dry flue gas is given [12].

$$C_{P_{fg}} = (0.3+0.000038T_{fur})\ \text{kcal/kg℃} \qquad (4.46)$$

Where: T_{fur} = Furnace temperature =722.6℃

$C_{P_{fg}}$ = specific heat of dry flue gas

Substituting the value of furnace temperature in the equation (4.15) specific heat of the flue gas is 1.38kJ/kg ℃).

4.9.5 Energy Loss Due To Dry Flue Gas

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

$$Q_{fl} = m_{flue} c_{pf}(T_{flue} - T_{amb}) \qquad (4.47)$$

Where: Q_{fl}: Heat loss due to sensible heat of the dry flue gas

m_f : Mass flow rate of fuel =0.94kg/sec

c_{pfl} : Specific heat capacity of flue gas=1.38 kJ/kg℃

T_{fl}: Fuel Gas temperature =400℃

T_{amb}: Ambient temperature =25℃

$$Q_{fl} = 0.94 \times \frac{1.38\text{kJ}}{\text{kg}}\text{℃}(400\text{℃} - 25\text{℃}) = 486.45\ \text{kW}$$

Table 4.6: Summary of Input-Output Energy

Input energy [kw]	Output energy [kw]
Fuel due to its heat content = 3098.232kW	Heat loss due to dry flue gas = 486.45 kW
Energy due to Pre-heating = 7.78 kW	Heat loss due to hydrogen in furnace fuel oil = 196 kW
Combustion air = 0 Kw	Heat loss due to moisture in air = 6. Kw
	Heat loss due to moisture in fuel = 192.2kW
$\sum_{i=1}^{3} 3106.012$	$\sum_{i=1}^{4} 880.65$

4.9.6 Calculation of the Combustion efficiency at 15% Excess Air

Using Equation (4.48) the combustion efficiency of the furnace at 15% of excess air is given by

$$\eta_{comb\ GCV} = (1 - \frac{\sum_{i=1}^{4} 880.65}{\sum_{i=1}^{3} 3106.012}) \times 100\% = 72\%$$

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

CHAPTER FIVE

INVESTIGATION ON ENERGY UTILIZATION PERFORMANCE AND ENERGY MODELING

5.1 Introduction

Zeway Caustic Soda Share Company (ZCSSC) uses heavy fuel oil and electricity to produce quicklime. Thermal energy is used to burn limestone pebbles after being combusted in the furnace inside a kiln of 42 m length. The consumption of heavy fuel oil in the furnace per unit production of quicklime is an important indicator for investigating the energy utilization performance of the factory. Similarly, electric energy is used utilized to drive the various electrically driven equipment in the production of quicklime systems and investigating the electric energy utilization per unit production of quicklime, it is another very important energy performance indicator. The consumption of fuel oil and electricity (also studying the corresponding energy bill) per unit of production of quicklime is an important indicator of the energy performance of the factory. Thus, investigating the energy performance of the factory will help in revealing the energy consumption, energy cost, and data for potential energy saving analysis of ZCSSC. In addition, modeling the past and present energy performances of the factory will help to predict future energy demand estimation and energy budget allocation for better energy management of the factory. Furthermore, developing and implementing energy monitoring, targeting, and reporting for ZCSSC greatly helps the factory to minimize the energy expenditure in the production of quicklime and help in maximizing its profit. In this chapter, the points discussed above are investigated as outlined below.

5.1.1 Energy Bill Analysis of ZCSSC

Thermal and electrical energies are used for the production of Quicklime in ZCSSC and so, the factory pays high cost for both energy sources. The energy bills show that as the factory paid 45718575 and 1240734 Birr for furnace oil and electricity respectively for the selected audit year (from October 2008 to April 2011 E.C). The bill analysis is necessarily dependent on the paid money to the used energies by the factory. Bills and all energy consumption data lists of the factory are obtained from the factory logbook which is collected for the past four years. From these only 30-months (from October 1st, 2008 E.C to April 30th 20011 E.C). After the collection of energy consumption, energy cost and production data monitoring process are undertaken to study and analyze the data and also to understand what is happening in the factory. The data is presented in Appendix A.

5.1.1.1 Fuel oil consumption pattern

Demands made on the nation's fuel oil resources are sources of energy in the burning limestone pebble period have exceeded use when restriction of industry demand was necessary. Under conditions of rising demand and increasing costs, fuel oil prices have advanced with the rising movement of the general price level. Relative changes in prices, however, have differed so that the structure of fuel prices has undergone considerable alteration.

New facilities have not only made possible increases in the present and future fuel-saving opportunities but have also contributed heavily to the high volume of investment in recent years. This article analyzes the fuel oil consumption patterns of the ZCSSC the more important improvements in the performance of energy management. The data is presented in Appendix A.

The chronological consumption of the fuel oil type used by the industrial sector in ZCSSC is presented in Figure (5.1). This graph shows fuel oil consumption on the per product of the Quicklime basis for each individual year and for all fuels taken together. In these terms, consumption in 2008 was fractionally higher than that of 2010 and 2009 & 2011 lower than two years and depend on this, it can be used to develop fuel oil &electricity demand modeling equation that is used to predict the fuel oil & electricity demand required to forecasting.

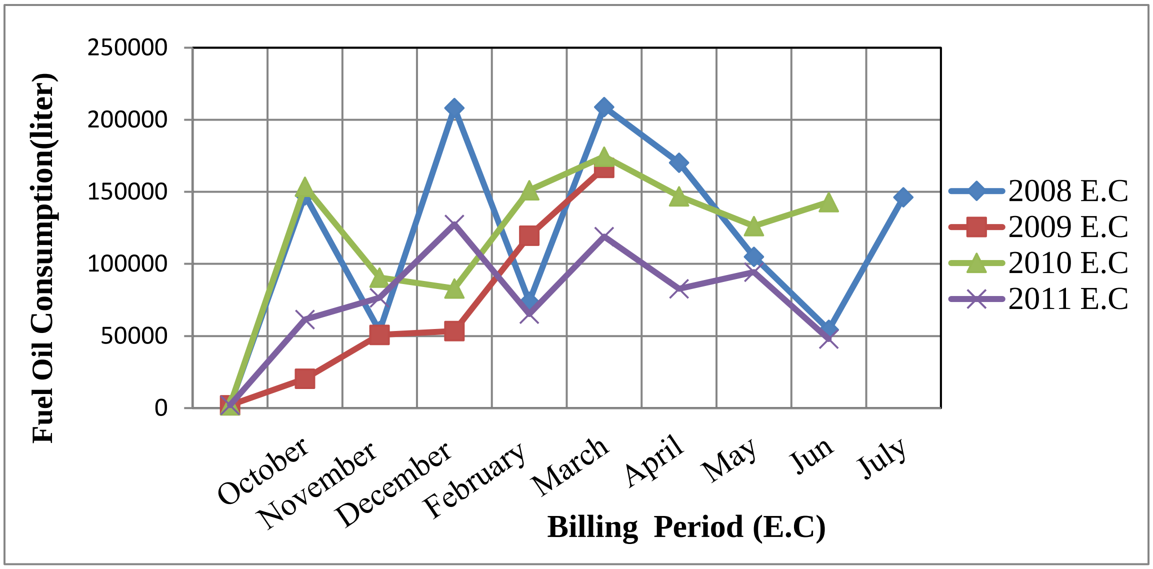

Figure 5.1: Monthly Fuel Consumption of ZCSSC from 2008-2011 E.C

5.1.1.2 Monthly Thermal Energy Intensity Pattern of ZCSSC

Monthly thermal energy utilization per unit of production or thermal energy intensity of the factory is defined as the average monthly energy needed to produce one kilogram of quicklime product and is that is given by the following equation [20].

$$\mathrm{MTEI} = \frac{\mathrm{GCV} \times \rho_f \times \text{monthly fuel used liters}}{\text{mass of quicklime produced in a monthly}} \tag{5.1}$$

Where: MTEI: Monthly thermal energy intensity

GCV: Gross calorific value of fuel in kJ/kg quicklime

ρ_f: Density of heavy fuel oil (kg/m^3)

Furnace oil parameters to be used for determining thermal energy consumption acquired by the experimental test are:

- Calorific valve =18500 BTU/LB=18500×2.326 =43031 kJ/kg
- The density of heavy fuel oil = 976 kg/m^3
- Ash = 6.28% & Moisture content =90.38%

The collected data on mass of production of quicklime from ZCSSC logbooks to get the thermal energy consumption per unit of production are indicated in Appendix A. Substituting these data from [Appendix A] in equations (5.1) thermal energy intensity was calculated for the billing years of 2008 - 2011 and the value are given in Table 5.1.

Table 5.1: Monthly Thermal Energy Intensities of ZCSSC (MJ/kg quicklime***)***

Billing period (E.C)	Production of Quicklime (kg)	Thermal energy intensity (Y)	Billing period (E.C)	Production of Quicklime (kg)	Thermal energy intensity (Y)
Oct-08	849000	7298459	Oct-10	913000	5887549
Nov-08	284200	7897451	Nov-10	538680	7423563
Dec- 08	1291000	6770109	Dec-10	493440	8141782
			Jan-10	897950	5479761
Feb-08	420000	7383613	Feb-10	1037400	7064118
Mar-08	641000	13677518	Mar-10	873000	7088459
Apr-08	933000	7655559	Apr-10	750300	3936285
May-08	605000	7287778	May-10	850000	7298700
Jun-08	306730	7453820	Oct-11	833000	3859722
Jul-08	812000	7564072	Nov-11	910000	5879761
Aug-08	117250	7897382	Dec-11	358210	7635954
Oct-09	108000	7923855	Jan-11	453580	11002861
Nov-0	268140	7963878	Feb-11	492500	7064118
Dec-09	284200	7897451	Mar-11	847640	4673402
Jan-09	643100	7803342	Apr-11	686400	2936285
Feb- 09	976000	7169235			

Thermal energy consumption data of the factory are listed within the factory logbook for many years. From these October 1st 2008 E.C to April 30th 2011E.C data regarding the factory consumption of furnace oil, electricity, and produced Quicklime are presented but this subtopic determined only monthly thermal energy consumption. The following figures, figure 5.2, 5.3, 5.4, and 5.5 provide monthly thermal energy intensities of ZCSSC. The figures shows a huge quantity of heavy fuel consumption per the production of quicklime. the data be presented graphically since Graphs generally provide an effective means of developing the energy-production relationships, which explain what is going on in the plant. These shows how to manage its thermal energy consumption and corresponding energy bill to be profitable.

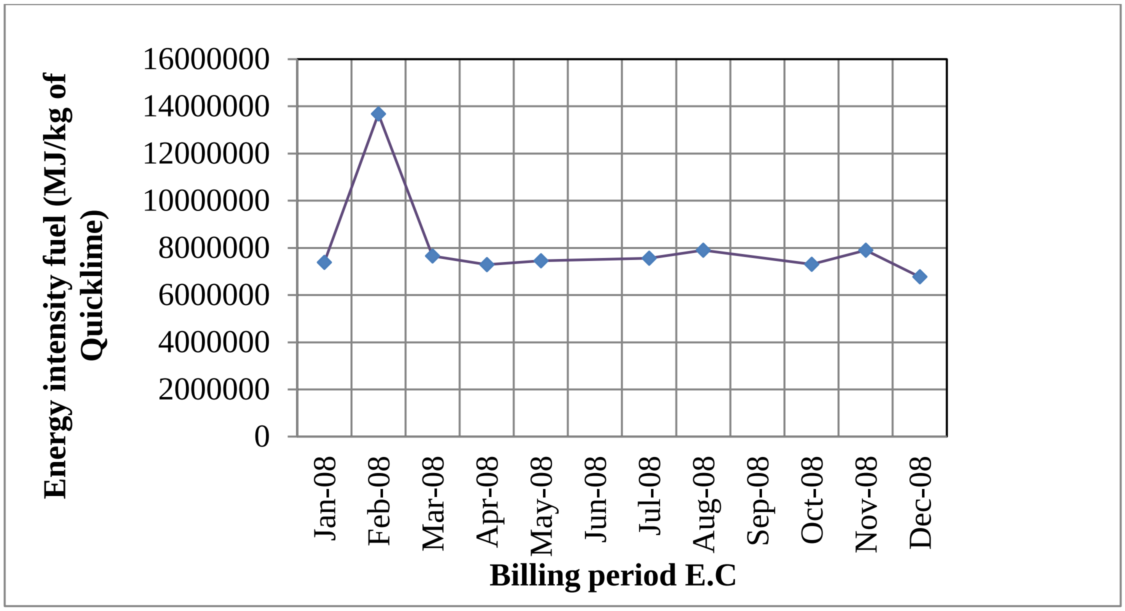

Figure5.2: Thermal Energy Intensities of ZCSSC at 2008

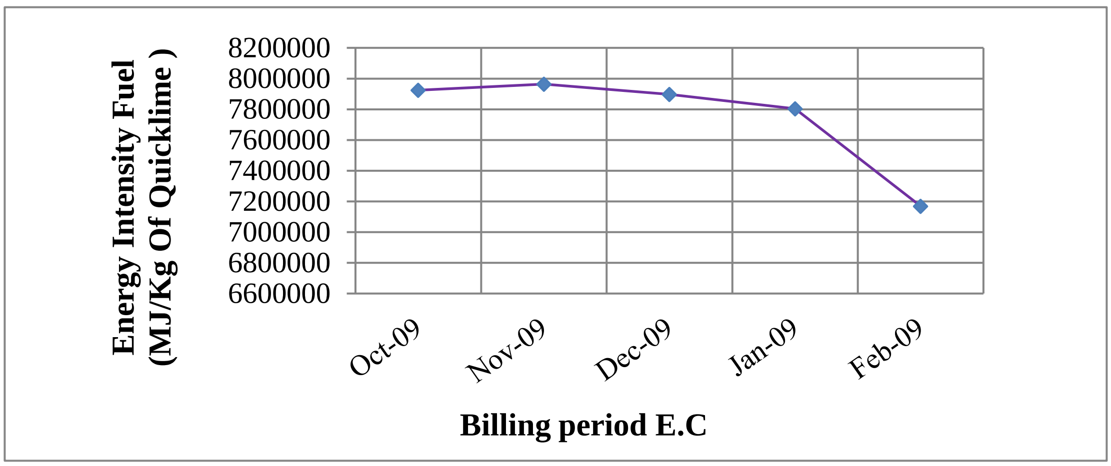

Figure5.3: Thermal Energy Intensities of ZCSSC at 2010 E.C

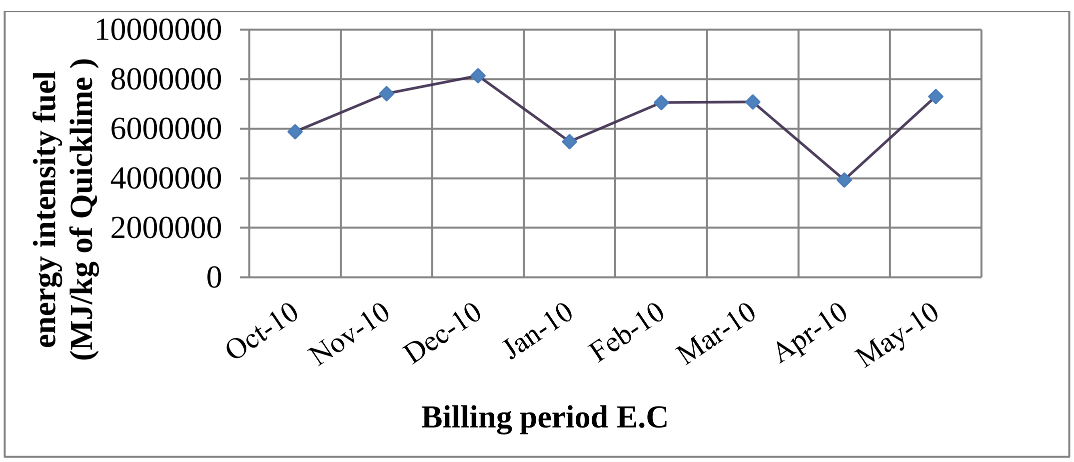

Figure 5.4: Thermal Energy Intensities of ZCSSC at 2010E.C

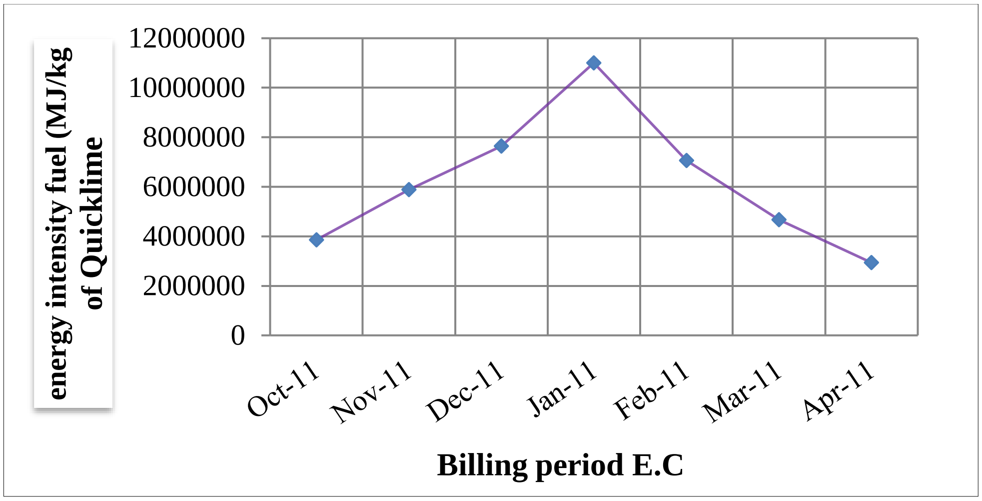

Figure 5.5: Thermal Energy Intensities of ZCSSC at 2011 E.C

5.1.1.3 Monthly Quicklime fuel oil cost analysis of ZCSSC

The prices are set by market conditions (supply & demand), but within any geographical area, they are regular. The price is simply a uniform change per liter, so the total cost is the number of liters used times the price per liter. The specific gravity and the gross calorific value (GCV) of furnace oil are 976 kg/m^3 and 43013 kJ/kg, respectively. The price is taken as 14.67 Birr/liter according to the Ethiopian petroleum agency price. Hence, most of the time fuel oil supply to the factory disturbs and this leads to downtime. The cost of fuel oil is varying in different country .equation (5.2) give to monthly fuel oil consumption costs [21].

$$\text{MFC} = C_f \times \text{monthly fuel used in Liter} \quad (5.2)$$

where: MFC $-$Monthly Fuel cost &

C_{fuel} $-$Average monthly cost fuel (Birr/liter)

The cost of fuel was calculated using equation 5.2 which is tabulated in Table 5.3 and also indicated in Figure 5.6.

Table 5.2: Monthly Fuel Oil Consumption Cost (Birr/liter) at ZCSSC

Billing period (E.C)	Production of Quicklime (kg)	Cost of Fuel [Birr] (Y)	Billing period (E.C)	Production of Quicklime (kg)	Cost of Fuel [Birr] (Y)
Oct-08	849000	1574903	Oct-10	913000	2253768
Nov-08	284200	2221451	Nov-10	538680	1329748
Dec- 08	1291000	570460.9	Dec-10	493440	1218072
Jan-08			Jan-10	897950	2216617
Feb-08	420000	2228333	Feb-10	1037400	2560854
Mar-08	641000	1815404	Mar-10	873000	2155027
Apr-08	933000	1120638	Apr-10	750300	1852139
May-08	605000	581098.9	May-10	850000	2098252
Jun-08	306730	1561085	Oct-11	833000	902205
Jul-08	812000	1562152	Nov-11	910000	1123522
Aug-08	117250	1574903	Dec-11	358210	1869742
Oct-09	108000	299048	Jan-11	453580	955832.1
Nov-0	268140	746219.8	Feb-11	492500	1743974
Dec-09	284200	784316.9	Mar-11	847640	1215751
Jan-09	643100	1753637	Apr-11	686400	1384284
Feb- 09	976000	2445137			

The following graph is drawn based on Figure 5.6. After data collection of thermal energy consumption, energy cost and production of quicklime, monitoring process and forecasting were undertaken to study and to analyze the data and also to represent that particular year of study.

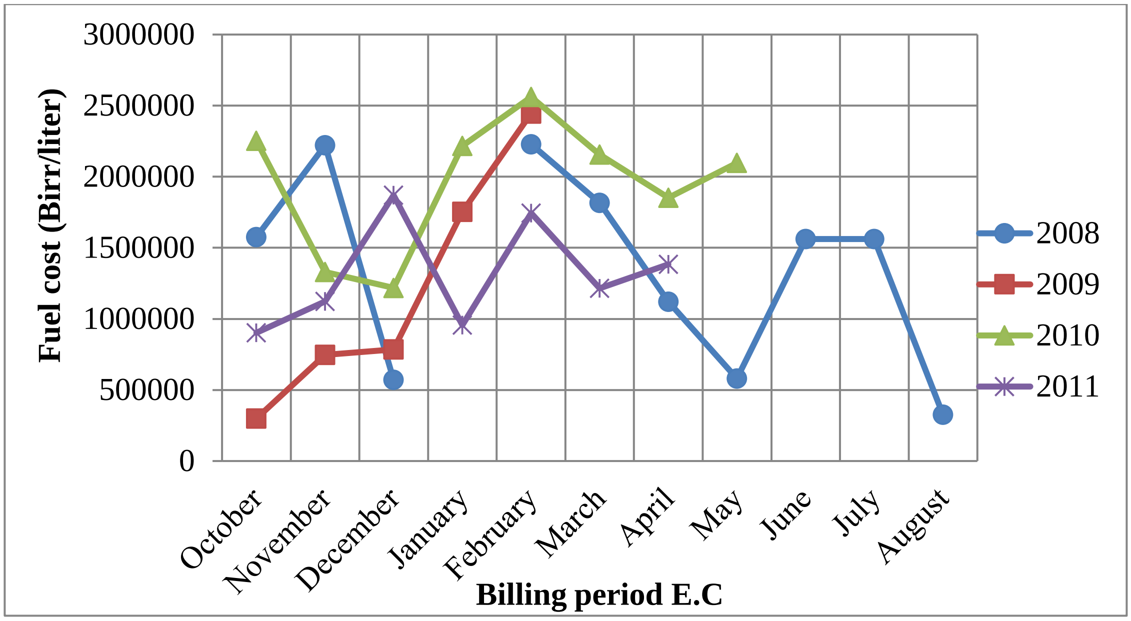

Figure 5.6 Monthly Cost of Fuel Consumption (Birr/Liter) ZCSSC 2008-2011E.C

5.2 Regression Analysis

Regression analysis is the most common method for a statistical approach based upon historical consumption and factors of influence. Regression models quite well represent the consumption of energy carries and statistical process control techniques such as the CUSUM plot [22].

Regression analysis is used to developed correlations using different factors such as consumption of energy carries and statistical process control (SPC) method. It is a means of fitting all the best lines through a series of observations.

Table 5.3: Linear Regression for Predication Energy Consumption

Billing period(E.C)	X	Y	$(X_i - X)$	$(Y_i - Y)$	$(X_i - X)^2$	$(Y_i - Y)^2$	$(X_i - X) \times (Y_i - Y)$
October	849000	377.8092	2.23E+05	5.68E+01	4.98E+10	3.22E+03	1.27E+07
November	284200	372.4138	-3.42E+05	5.14E+01	1.17E+11	2.64E+03	-1.76E+07
December	1291000	346.3362	6.65E+05	2.53E+01	4.42E+11	6.40E+02	1.68E+07
February	420000	385.7143	-2.06E+05	6.47E+01	4.24E+10	4.18E+03	-1.33E+07
March	641000	421.2168	1.51E+04	1.00E+02	2.27E+08	1.00E+04	1.51E+06
April	933000	396.463	3.07E+05	7.54E+01	9.43E+10	5.69E+03	2.32E+07
May	605000	376.0066	-2.09E+04	5.50E+01	4.38E+08	3.02E+03	-1.15E+06
June	306730	38.73113	-3.19E+05	-2.82E+02	1.02E+11	7.97E+04	9.01E+07
July	812000	399.0148	1.86E+05	7.80E+01	3.46E+10	6.08E+03	1.45E+07
August	117250	96.7142	-5.09E+05	-2.24E+02	2.59E+11	5.03E+04	1.14E+08
Total	6259180	3210.42	0.00E+00	3.00E-05	1.14E+12	1.66E+05	2.41E+08

To estimate the regression equation the production of quicklime (X) and energy consumption (Y) values are shown in the table above which is directly taken from the given data in Zeway Caustic Soda Share Company. To estimate the production of quicklime and energy consumption first the regression equation must be developed based on monthly collect data from the factory.

$$b = \overline{Y} - m\overline{X} \tag{5.4}$$

$$\partial_X = \frac{\sum(Xi - \overline{X})^2}{n} \tag{5.5}$$

$$\partial_Y = \frac{\sum(Yi - \overline{Y})^2}{n} \tag{5.6}$$

$$R^2 = \{\frac{1}{N} \times \sum[(Xi - \overline{X}) \times (Yi - \overline{Y})]\}^2 \tag{5.7}$$

$$e = Y - \widehat{Y} \tag{5.8}$$

Where: $\overline{X}$: The mean of X total monthly produced by quicklime (kg)

$\overline{Y}$: The mean of Y total of energy consumption (kJ / kg of quicklime)

SS_{XY}: The sum total of energy consumption and production of quicklime

SS_{XY} : The sum total squared production of quicklime

Y: electrical & thermal energy of consumption (kJ) and X: production of quicklime (kg)

R:Coefficient of determination & ∂_X : standard deviation of production quicklime

∂_Y : the standard deviation of electrical energy consumption, e: Error or residual &

$\widehat{Y}$: The predictive valve of energy consumption.

5.2.1 Thermal Energy Performances Modeling at ZCSSC

Energy models may be used for a variety of reasons, the most common being the determination of factory energy supply requirements (macro-scale) and the change in energy consumption of a particular residence due to an upgrade or addition of technology (micro-scale) [23]. A thermal energy model is a mathematical tool done necessary based on the system approach and the best model should be used to estimate thermal energy consumption in Zeway Caustic Soda Share Company (ZCSSC). Hence, this section aims to attempt to model the thermal energy consumption of Zeway Caustic Soda Share Company using regression analysis developed using the appropriate input data collected from the factory logbook. In this section energy model analysis and study energy monitoring, targeting, and reporting conducted at ZCSSC are discussed as outlined below.

The main procedures to perform thermal energy modeling

- Study present and past thermal energy consumption pattern of the factory;
- Develop thermal energy performance modeling using CUSUM analysis
- Identify energy target towards which the future energy consumption trend of the factory is planned;
- Identify means for a reduction in thermal consumption;
- Predict the monthly energy consumption and bills
- Predict the annual energy cost
- Forecast the future energy demand and budge for the factory**.**

5.2.2 Developing Thermal Energy Performance of the Regression Modeling

Regression analysis is the appropriate technique for investigating data and forecasting the happening of the dependent variable i.e. energy consumption in this case study. Refining of zeway caustic soda share company sample to obtain information that facilitates these functions involves regression analysis. For many instances, linear regression of thermal energy consumption against a single independent variable (monthly production quicklime) generates a valid thermal energy performance model.

Table 5. 4: Sample Termal Energy Consumption for ZCSSC 2008-2011E.C**.**

Billing period (E.C)	Production of Quicklime (kg)	Thermal energy consumptio n(MJ)	Billing period (E.C)	Production of Quicklime (kg)	Thermal energy consumption(MJ)
Oct-08	849000	6196.39153	Oct-10	913000	6449.53978
Nov-08	284200	2244.4555	Nov-10	538680	3805.29911
Dec- 08	1291000	8740.21132	Dec-10	493440	3485.71824
Feb-08	420000	3101.11762	Jan-10	897950	6343.22486
Mar-08	641000	8767.28886	Feb-10	1037400	7328.31606
Apr-08	933000	7142.63624	Mar-10	873000	6166.97566
May-08	605000	4409.10572	Apr-10	750300	5300.20879
Jun-08	306730	2286.31025	May-10	850000	6004.502
Jul-08	812000	6142.02654	Oct-11	833000	3215.14808
Aug-08	117250	925.968	Nov-11	910000	5350.58226
Oct-09	108000	855.776325	Dec-11	358210	2735.27524
Nov-0	268140	2135.43418	Jan-11	453580	4990.67762
Dec-09	284200	2244.4555	Feb-11	492500	3479.07815
Jan-09	643100	5018.32946	Mar-11	847640	3961.36237
Feb- 09	976000	6997.17315	Apr-11	686400	2015.46596

After thermal energy consumption data collected is to gain more understanding of the relationship between energy and production, and to provide us with some basis for performance measurement. This specifies that a straight line can represent interchange between the points in a scatter diagram of Thermal energy consumption vs. quicklime production approximately and, the effect of increased production on energy consumption can be represented by a regression equation [17].

$$\mathrm{Y} = mX + \mathrm{b} \qquad (5.9)$$

Where: Y : fuel energy consumption (MJ)

X : quicklime production (kg)

b: Non-associated energy (MJ)

Welcome to Minitab, press F1 for help.

Regression Analysis: Thermal energy versus Production of Quicklime

The regression equation is

Thermal energy consumption (MJ) = 0.06228 Production of Quicklime (kg) + 551.7 0.

S = 1209.80   R-Sq = 70.6%   R-Sq(adj) = 69.5%

Where: S: standard error,

R-Sq: correlation coefficient &

adj R-Sq: Adjusted correlation Coefficient

As shown in Fig 5.7, the fuel consumption for producing 19473720 kg of quicklime is indicated to be 255811844.3 liters or 551.7 GJ which is extremely higher compared to the quantity produced.

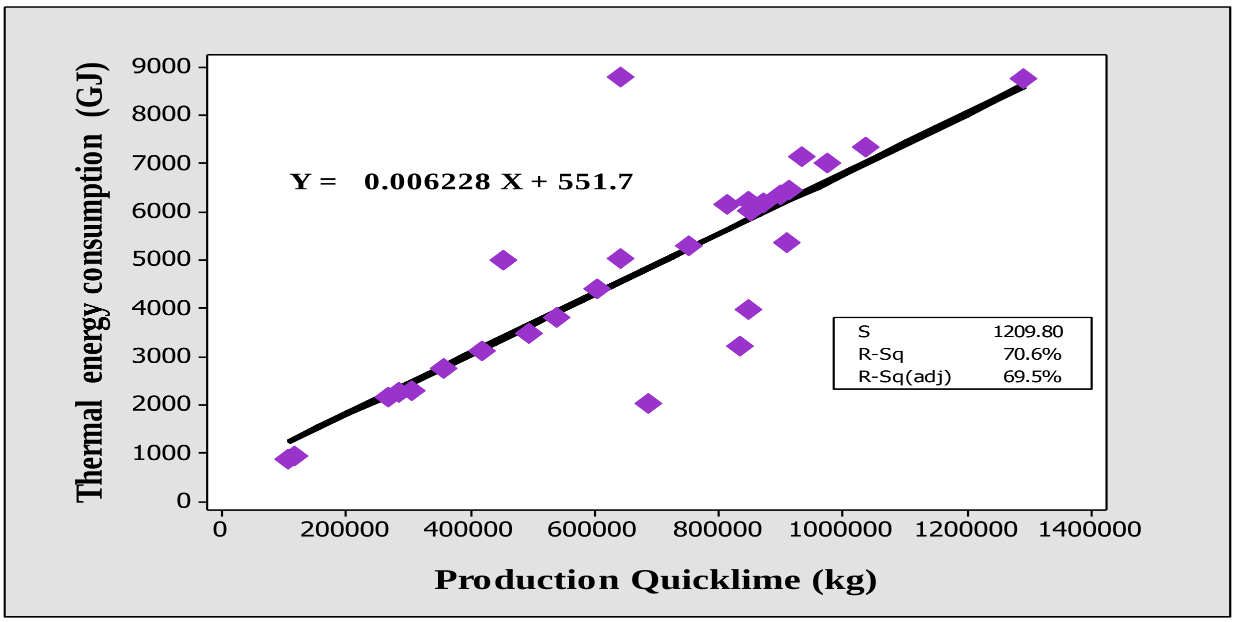

Figure 5.7: Regression Analysis Thermal Energy of ZCSSC Energy Consumption

Specialized Minitab 14 software is used to evaluate the quantitative results that allow the ZCSSC and its levels which concern for energy management modeling program. As a result, ZCSSC achieved an average classification of R^2 = 70.6% which indicates a low level of energy management. Based on the value of adjustedR^2, the amount of variation described by the estimated regression line is approximately 0.695 or 69.5%. The measure of the strong relationship between thermal energy consumption and production Quicklime variables is measured by the Coefficient of the Correlation coefficientR^2 [24].

5.2.3 Base Period Performance Estimation Thermal Energy Consumption at ZCSSC

Information collected by measuring a building's energy performance for a minimum of 12 months selected from 30 months preferred will establish a baseline for energy consumption. An energy baseline serves as a reference point for evaluating future energy saving efforts. The total Thermal energy consumption data and quicklime production data are used to develop a regression equation of the baseline (best fit) based on the data of each month. This is based on the best historical performance selected from Table 5.8 Curve fitting of a base period of Thermal energy used by kiln and furnaces is shown in Figure.5.8 and the equation is given by Energy Baseline

$$Y_{\text{baseline energy}} = 0.006520X + 874.3 \tag{5.10}$$

$R^2 = 0.73$ (coefficient of determination)

S = 1249.47   R-Sq = 73.4%   R-Sq(adj) = 70.7%

Figure 5.8 shows a new energy performance. It is indicating the factory done by these predictions is minimizing fuel oil consumption and loss of thermal energy. One point lies above (relatively higher energy consumption) the sample is not screening.

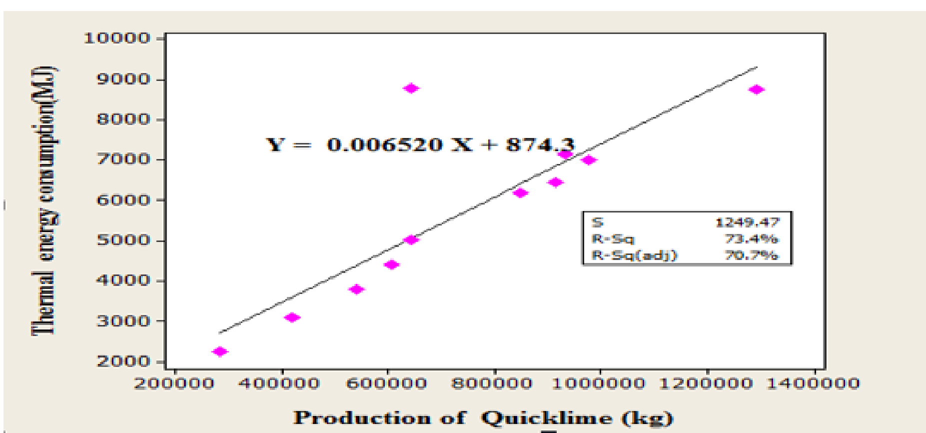

Figure 5.8: Linear Regression of the Baseline Period

5.2.4 Developed CUSUM Thermal energy consumption of performance analysis model

The CUSUM analysis indicates, for the case study, of the zeway caustic soda share company had an improvement from 2008-2011E.C. This information could be valuable when it develops an energy management program in the industry. This indicator and its chart are used to monitor the trend of the company equipment energy utilization and regarding the variation of energy consumption, for a given base period. This is an important part of the performance estimation measures used in continuous improvement efforts that covered the literature [11].In this paper, a complete CUSUM quality control chart for monitoring energy use performance is given.

5.2.4.1 CUSUM Analysis

CUSUM analysis is well suited to the assessment of procedures with the outcome, but accurate and appropriate standards of practice must be determined before the assessment to ensure correct identification of performance. CUSUM analysis is a method of continuously evaluating the performance of the factory against a predetermined standard to detect adverse trends and to allow for early intervention.

The CUSUM Analysis has the following procedures which are list below.

- Plot the energy – production graph for the first 12 months
- Draw the best fit straight line
- Derive the equation of the baseline, Y=mX+b
- Calculated the expected energy consumption based on the equation.
- Calculated the difference between actual and calculated energy use
- Compute CUSUM
- Plot the CUSUM graph and
- Estimate the saving accumulated from the use of the heat recovery system

Table 5.5: CUSUM Calculation Thermal Energy Consumption 2008-2011E.C

Billing period (E.C)	Production Quicklime(kg)	Thermal energy consumption(M	Y=0.00628 X + 551.7	Variance energy(MJ)	CUSUM
Oct-08	849000	6196.39153	5883.42	312.97153	312.972
Nov-08	284200	2244.4555	2336.476	-92.0205	220.951
Dec- 08	1291000	8740.21132	8659.18	81.03132	301.982
Jan-08	420000	3101.11762	3189.3	-88.18238	213.8
Feb-08	641000	8767.28886	4577.18	4190.1089	4403.91
Mar-08	933000	7142.63624	6410.94	731.69624	5135.61
Apr-08	605000	4409.10572	4351.1	58.00572	5193.61
May-08	306730	2286.31025	2477.9644	-191.6542	5001.96
Jun-08	812000	6142.02654	5651.06	490.96654	5492.92
Jul-08	117250	925.968	1288.03	-362.062	5130.86
Aug-08	108000	855.776325	1229.94	-374.1637	4756.7
Oct-09	268140	2135.43418	2235.6192	-100.185	4656.51
Nov-0	284200	2244.4555	2336.476	-92.0205	4564.49
Dec-09	643100	5018.32946	4590.368	427.96146	4992.45
Jan-09	976000	6997.17315	6680.98	316.19315	5308.65
Oct-10	913000	6449.53978	6285.34	164.19978	5472.85
Nov-10	538680	3805.29911	3934.6104	-129.3113	5343.54
Dec-10	493440	3485.71824	3650.5032	-164.785	5178.75
Jan-10	897950	6343.22486	6190.826	152.39886	5331.15
Feb-10	1037400	7328.31606	7066.572	261.74406	5592.89
Mar-10	873000	6166.97566	6034.14	132.83566	5725.73
Apr-10	750300	5300.20879	5263.584	36.62479	5762.35
May-10	850000	6004.502	5889.7	114.802	5877.16
Oct-11	833000	3215.14808	5782.94	-2567.792	3309.36
Nov-11	910000	5350.58226	6266.5	-915.9177	2393.45
Dec-11	358210	2735.27524	2801.2588	-65.98356	2327.46
Jan-11	453580	4990.67762	3400.1824	1590.4952	3917.96
Feb-11	492500	3479.07815	3644.6	-165.5219	3752.44
Mar-11	847640	3961.36237	5874.8792	-1913.517	1838.92
Apr-11	686400	2015.46596	4862.292	-2846.826	-1007.91

From Figure 5.9, it can be seen that the CUSUM graph fluctuates around the upper zero lines for several months and then drops sharply after months 2-6. This suggests that the heat recovery system took almost several months to warrant and reach proper operating conditions, after which Steady savings have been achieved. This useful technique not only provides a trend line, but it also calculates saving /losses to date and shows when the performance changes.

The Cumulative Sum Control Chart of the industry for the year 2008 – 2011 E.C is presented in Fig. 5.9. Hence, this graph explains upward gradients signify a persistent tendency to use more energy than expected. This control scheme (for individual observations) gives an out of control signal at 30th observation and thus for small shifts showing an upward trend, which means higher Thermal energy consumption for the same production about the energy consumption trends. Based on the graph 5.9 number observation (2-6) (see table 5.8) saving of 1319.25KJ/kg

1007.91-2327.46) kJ/kg have been accumulated in the last 5 months. This represents savings of almost 6.41% of energy consumption.

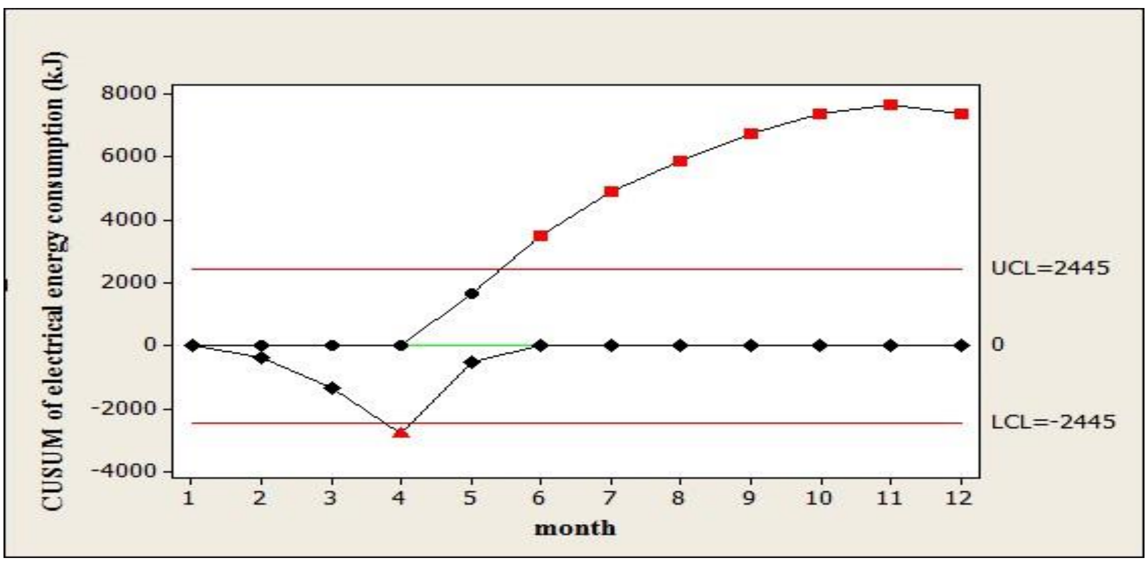

Figure 5.9: CUSUM Chart of Thermal Energy Consumption 2008-2011 E.C

The CUSUM technique is a simple but remarkably powerful statistical method, which high-light small differences in energy efficiency performance. Regular use of the procedure allows the energy manager to follow factory performance and spot any trends early.

5.3 Electricity Consumption Pattern

This paper is studied Electric Energy consumption assessments in a Quicklime production plant. Monthly electricity consumption analysis data is the guideline for reducing electric energy consumption and identifying potential electricity-saving opportunities in the factory collected from the company logbook. The purpose of electrical energy consumption analysis was to identify changes observed in the energy consumption of ZCSSC and develop a regression model for predicting its future electrical energy consumption.

Figure 5.10 shows the electricity consumption of ZCSSC is decreased from year to year starting from 2008 to 2011E.C. This implies that more electricity was consumed in 2008 than in the next three years. In addition, the utilization of electricity in 2009 and 2010 was medium. Depending on this it can be used to develop electricity demand modeling equations to predict future electricity consumption in various energy modeling techniques.

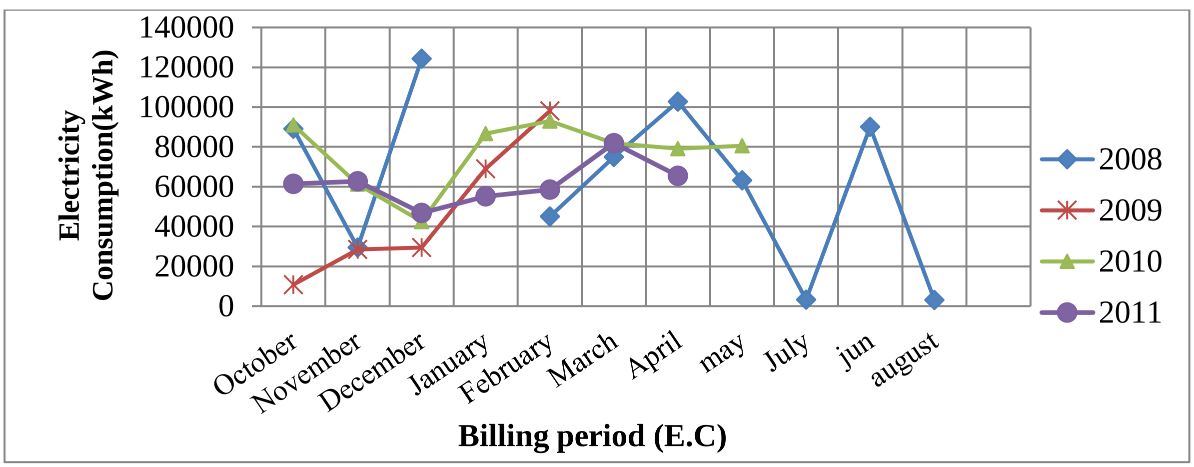

Figure 5.10: Monthly Electricity of Consumption (kWh) of ZCSSC from 2008-2011 E.C

5.3.1 Monthly Electrical Energy Intensity Consumption Pattern of ZCSSC

The monthly electricity energy consumption intensity of the factory is defined as the average monthly energy needed to produce one kilogram of quicklime. It is given by the following equation.

$$\text{MEEI}= \frac{\text{monthly electricity used kWh}\times 3600 \text{ sec}}{\text{monthly quicklime produced}} \quad (5.11)$$

Where: MEEI − Monthly electricity energy intensity

Substituting data from [Appendix A] in equations (5.11) & the factory specific energy consumption is determined in Table 5.6.

Table 5.6: Electrical Energy Intensity Of Consumption of ZCSSC (kJ/kg)

Billing period (E.C)	Production of Quicklime (kg)	electrical energy intensity (Y)	Billing period (E.C)	Production of Quicklime (kg)	electrical energy intensity (Y)
Oct-08	849000	377.8092	Oct-10	913000	358.8171
Nov-08	284200	372.4138	Nov-10	538680	409.6681
Dec- 08	1291000	346.3362	Dec-10	493440	310.0681
Jan-08			Jan-10	897950	347.5917
Feb-08	420000	385.7143	Feb-10	1037400	322.7299
Mar-08	641000	421.2168	Mar-10	873000	337.732
Apr-08	933000	396.463	Apr-10	750300	379.2019
May-08	605000	376.0066	May-10	850000	341.3647
Jun-08	306730	38.73113	Oct-11	833000	265.7863
Jul-08	812000	399.0148	Nov-11	910000	248.044
Aug-08	117250	96.71642	Dec-11	358210	470.3386
Oct-09	108000	360	Jan-11	453580	437.3209
Nov-0	268140	382.6359	Feb-11	492500	428.3452
Dec-09	284200	372.4138	Mar-11	847640	347.8363
Jan-09	643100	386.2541	Apr-11	686400	343.007
Feb- 09	976000	361.4754			

The electrical energy consumption data of the factory are listed within the factory logbook for many years. Starting from October 1st 2008 E.C to April 30th 2011E.C data regarding the consumption of furnace oil, electricity, and produced Quicklime of the factory are presented but in this section data monthly electrical energy consumption is considered. The following figures, figures 5.11, 5.12, 5.13 and 14 provide monthly electrical energy intensities of ZCSSC.

The following figures show the various amount of electrical energy consumption because of the production of quicklime and electrical consumption energy loss of variety for different reasons

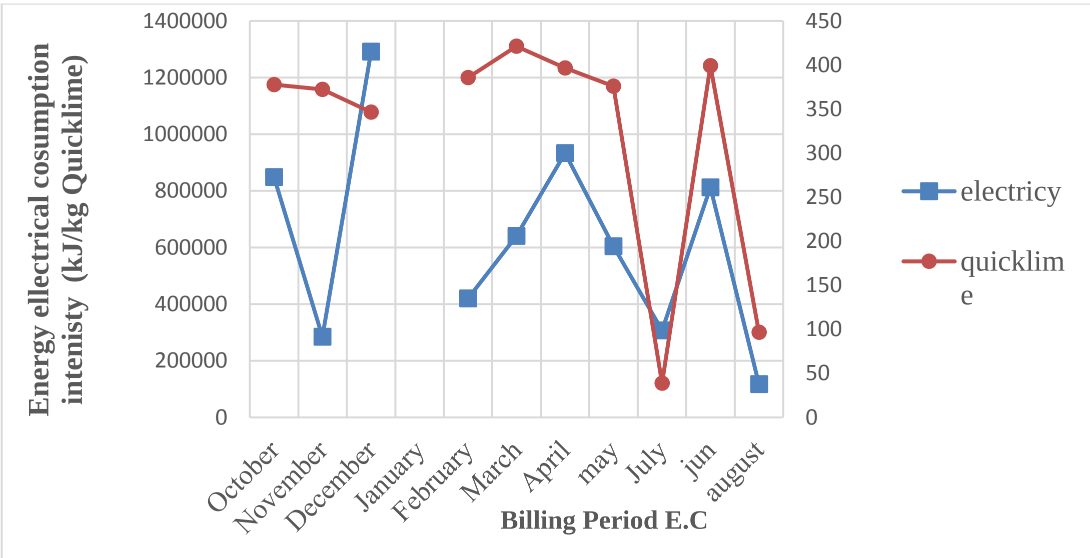

Figure 5.11: Energy Electrical Entensity (kJ/kg Quicklime)of ZCSSC 2008 E.C

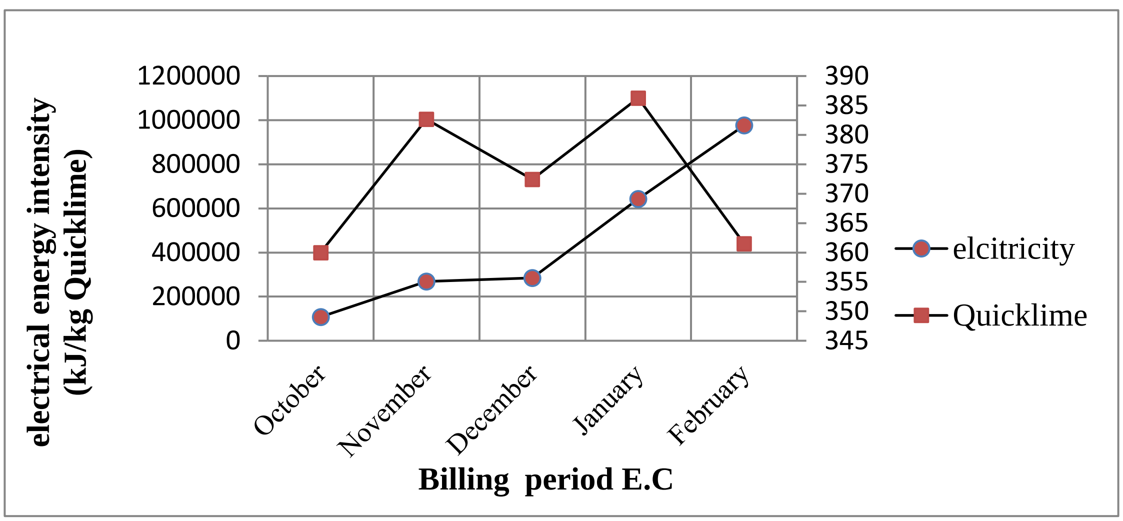

Figure 5.12: Energy Electrical Consumption Intensity (kJ/kg Quicklime) of ZCSSC 2009

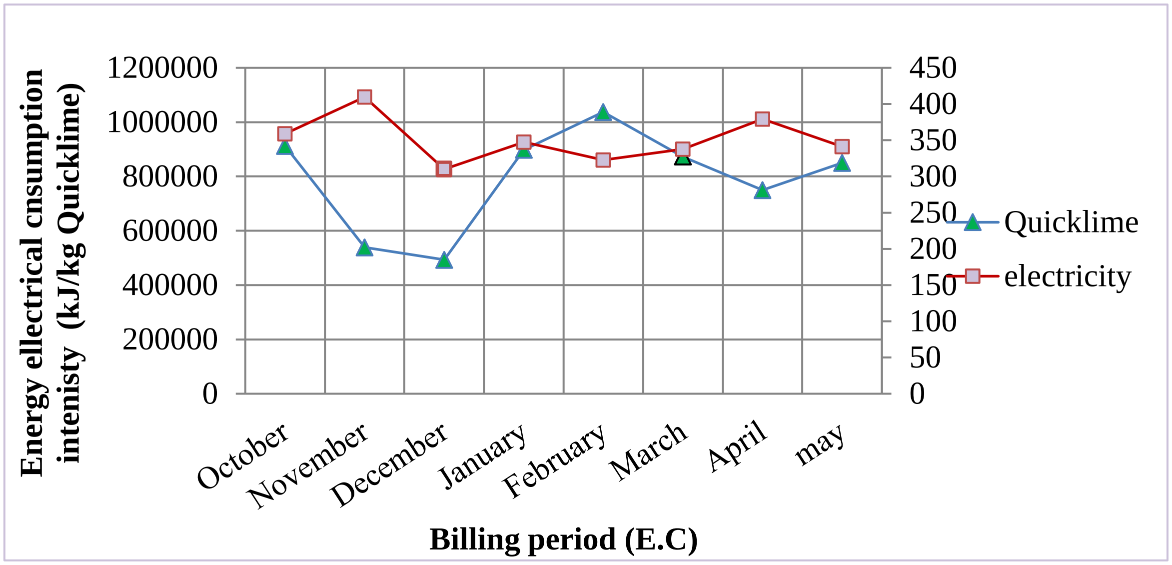

Figure 5.13: Energy Electrical Consumption Intensity (kJ/kg Quicklime) of ZCSSC 2010

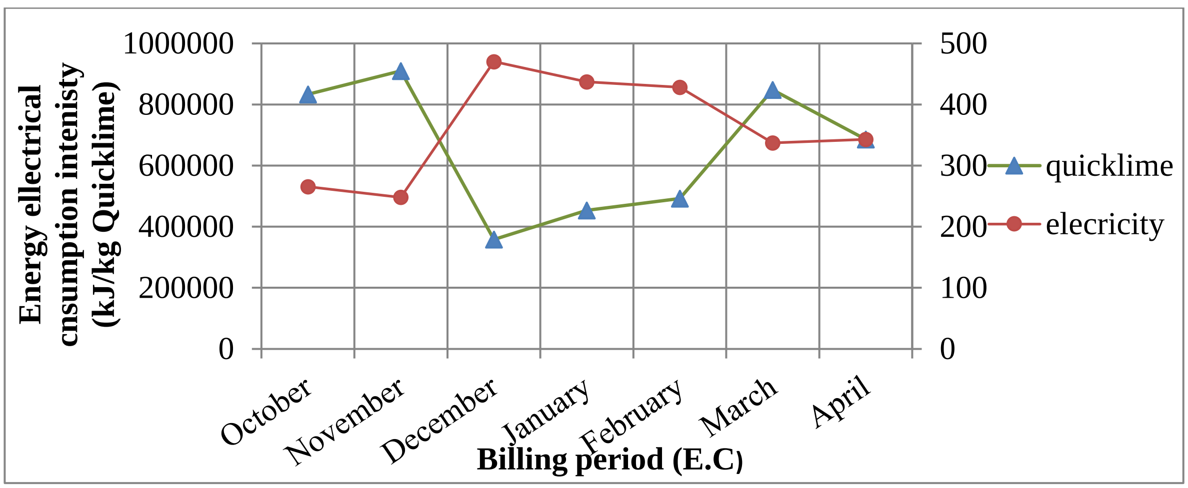

Figure 5.14: Energy Electrical Consumption Intensity (kJ/kg Quicklime) of ZCSSC 2011

5.3.2 Monthly Electrical Energy Cost Analysis in Quicklime Production of ZCSSC

The electricity consumption patterns are processed into monthly factory paid electrical energy intensity. The total cost of electricity consumption is the number of kilowatts per hour consumed times the price. Based on the voltage consumption and a number of phases (ZCSSC use different phases and high voltage lines) used in the factory, the cost of electricity varies from month to month and year to year. The collected data shows that as the factory consumes high voltage or electricity with a straight line increasing factor for paying the electricity consumed (in kWh) with a rate of 0.65 Birr/kWh [21].

Monthly Electricity consumption of costs obtains based on collected samples in the factory.

$$\text{MEC}= \mathrm{C_{ele}}\frac{\text{Birr}}{\text{kWh}} \times \text{monthly electric used in kWh} \tag{5.12}$$

Where: MEC $-$Monthly electric cost

$\mathrm{C_{ele}}$ $-$ Average monthly cost electricity (Birr/kWh)

We can calculate with these formulas or read directly from the factory logbook and tabulated in table 5.7 as follows.

Table 5.7: Monthly Electricity Cost (Birr/kWh) at ZCSSC

Billing period (E.C)	Production of Quicklime (kg)	electricity cost (Birr/kWh)(Y)	Billing period (E.C)	Production of Quicklime (kg)	electricity cost (Birr/kWh (Y)
Oct-08	849000	57915	Oct-10	913000	59150
Nov-08	284200	19110	Nov-10	538680	39845
Dec- 08	1291000	80730	Dec-10	493440	27625
Jan-08			Jan-10	897950	56355
Feb-08	420000	29250	Feb-10	1037400	60450
Mar-08	641000	48750	Mar-10	873000	53235
Apr-08	933000	66787.5	Apr-10	750300	51370.8
May-08	605000	41073.5	May-10	850000	52390
Jun-08	306730	2145	Oct-11	833000	39975
Jul-08	812000	58500	Nov-11	910000	40755
Aug-08	117250	2047.5	Dec-11	358210	30420
Oct-09	108000	7020	Jan-11	453580	35815
Nov-0	268140	18525	Feb-11	492500	38090
Dec-09	284200	19110	Mar-11	847640	53235
Jan-09	643100	44850	Apr-11	686400	42510
Feb- 09	976000	63700			

Figure 5.15 shows the electricity bill or Cost consumption per product of the Quicklime basis for each year and all electricity consumption has taken together. This graph used to express

electricity consumption with time residents to identify the best of the baseline model and also predict simply is to study in the future energy management, monitoring process, analyze the data, and represent it for a year to year and other advantages

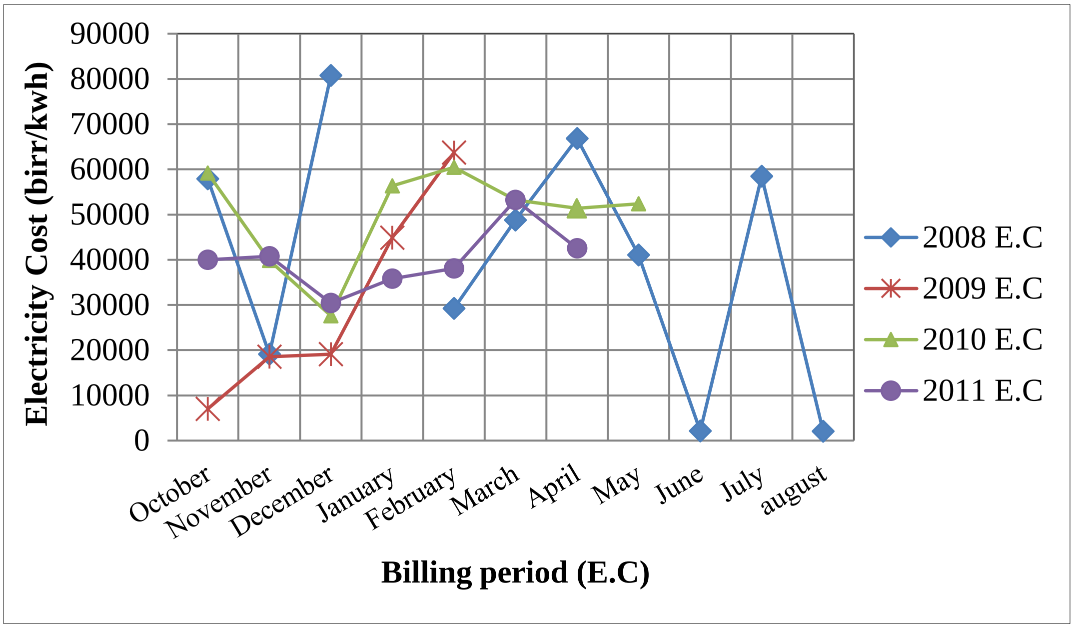

Figure 5.15: Monthly Electricity Cost (Birr/kWh) at ZCSSC 2008-2011 E.C

5.4 Electrical Energy performances modeling of ZCSSC

The energy model of Zeway Caustic Soda Share Company (ZCSSC) is undertaken using mathematical tools based on the system approach and the best model should be used to estimate electrical energy consumption. Hence, this section aims to attempt to solve Energy consumption modeling of the company seeks to quantify electric energy necessities as a function of the input parameters.

In this section energy model analysis and study energy monitoring, targeting, and reporting conducted at ZCSSC are discussed similar to thermal energy performance using modeling as outlined below.

5.4.1 Developing Electric Energy Performance Regression Model

In this study paper, we have to develop a simple and reliable mathematical model for monthly electricity usage forecasting for ZCSSC. This Regression analysis for forecasting monthly electricity usage of the factory similar to thermal energy principle and the linear regression technique has been employed using Minitab 14 software.

Table 5.8: Monthly Electric Energy Consumption Index of ZCSSC 2008-2011

Billing period (E.C)	Production of Quicklime (kg)	Electrical energy consumption (kJ)(Y)	Billing period (E.C)	Production of Quicklime (kg)	Electrical energy consumption (kJ)(Y)
Oct-08	849000	32076	Oct-10	913000	32760
Nov-08	284200	10584	Nov-10	538680	22068
Dec- 08	1291000	44712	Dec-10	493440	15300
Feb-08		16200	Jan-10	897950	31212
Mar-08	420000	27000	Feb-10	1037400	33480
Apr-08	641000	36990	Mar-10	873000	29484
May-08	933000	22748.4	Apr-10	750300	28451.52
Jun-08	605000	2966.515	May-10	850000	29016
Jul-08	306730	32400	Oct-11	833000	22140
Aug-08	812000	452.2333	Nov-11	910000	22572
Oct-09	117250	3888	Dec-11	358210	16848
Nov-0	108000	10260	Jan-11	453580	19836
Dec-09	268140	10584	Feb-11	492500	21096
Jan-09	284200	24840	Mar-11	847640	28566.32
Feb- 09	643100	35280	Apr-11	686400	23544

This specifies that reciprocity between the points in a scatter diagram of electric energy consumption versus quicklime production can be represented in the same manner of thermal energy performance approximately by a straight line and, in general, expressed [17].

Linear equation determines the modeling energy consumption for a given year using a known set of conditions production quicklime.

$$Y= MX + b \tag{5.13}$$

Where: Y: electric energy consumption

X: quicklime production (kg) and

b: non-associated (kJ)

Fig. 5.16 shows a scatter diagram of the Electrical energy consumption (Y) and quicklime production (X) best fits the regression equation. Above the scatter point in the straight line is the regime of poor energy efficiency, and below the scatter point in the straight line is the regime of an improved one. Using this, we can calculate the expected energy consumption for any level of production within the range of the data set. The non-related energy is the value of the intercept on the Y-axis is 715 kJ of the best-fit line to the distribution of data, also known as energy regression analysis. This implies baseload or used for heating equipment without production consume.

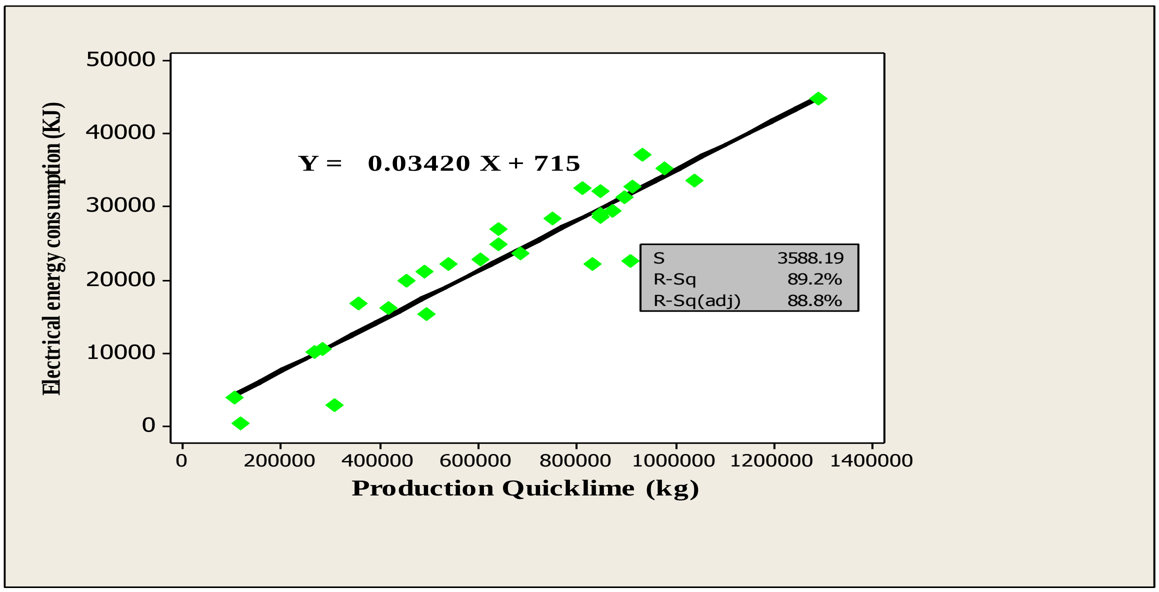

Figure 5.16: Electrical Energy Consumption Regression Analysis for a Productive Process

A value of R^2 and adjusted R^2 is 89 & 88.8% this explain similarly to thermal energy regression respectively, while $R^2 = 0$ indicates no "linear" relationship between the dependent and independent variables [24].

5.4.2 Developed Baseline Electrical Energy Consumption at ZCSSC

The baseline period is a new energy performance model for the selected data from the regression 12 months in the sample yield figure 5.16 selected in Table 5.5. Hence, the factory performed reliably for each point at which improve was implemented. The total electrical energy consumption and quicklime production data are used to improve the regression equation of the baseline (best fit) based on the ZCSSC collected data of each month also known as Energy Baseline. This is based on the best historical performance for two years.

$$Y_{\text{Baseline energy}} = 0.03459X+12170 \tag{5.15}$$

S = 1608.70   R-Sq = 97.9%   R-Sq(adj) = 97.7%

Figure 5.17 shows a new energy performance. It is indicating the factory done by these predictions is minimizing electricity consumption and reduce the loss of electrical energy shows the baseline best prediction because the factory is used the baseline to saving or improving the energy performance model. The same to that of thermal energy performance.

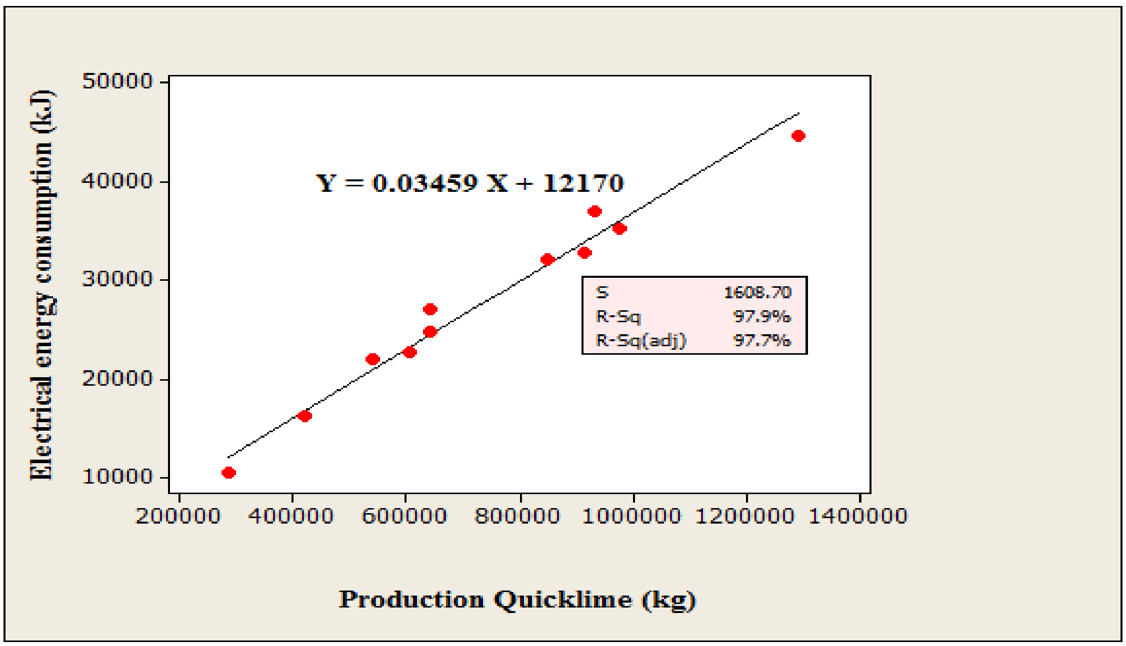

Figure 5.17: Linear Regression of the Baseline Period

5.4.3 Developed CUSUM Electrical Energy Consumption Performance Analysis model

The CUSUM analysis indicated for the case study, of zeway caustic soda share company had improvement from 2008-2011E.C. using the CUSUM, the amount of the energy consumed in excess of that wasn't consumed until the moment of its updating can be quantitatively determined. One of these control charts is Cumulative SUM (CUSUM), which has been widely used to monitor the variability of processes [25].In the current study, the Cumulative SUM of differences technique (CUSUM) was used to identify changes in historical electrical energy performance patterns.

5.4.4 CUSUM Technique for the Process Monitoring

The measured data for 12 months was used as a baseline to predict energy consumption and determine the baseline relationship to calculate expected energy consumption for any given production level.

CUSUM is a powerful technique for developing management information regarding the energy performance of a factory, or an energy-consuming system such as limekiln or furnace. It distinguishes between significant events affecting performance faults or improvements.

The baseline electrical energy performance management, for the selected months in table 5.8 (CUSUM calculation Electrical energy consumption) is used in CUSUM analysis.

The electrical energy of CUSUM analysis is the same thermal energy procedure. The CUSUM values are for are plotted in a time series shown in figure (5.18).

Table 5.9: Shows the CUSUM Calculation Electrical Energy Consumption (kJ) 2008-2011

Billing period (E.C)	Production Quicklime (kg)(X)	Electrical energy consumption (kJ)(Actual) (Y)	Y=0.0342X + 715 (Predict valve)	variance	CUSUM
Oct-08	849000	32076	29750.8	2325.2	2325.2
Nov-08	284200	10584	10434.64	149.36	2474.56
Dec- 08	1291000	44712	44867.2	-155.2	2319.36
Feb-08	420000	16200	15079	1121	3440.36
Mar-08	641000	27000	22637.2	4362.8	7803.16
Apr-08	933000	36990	32623.6	4366.4	12169.56
May-08	605000	22748.4	21406	1342.4	13511.96
Jun-08	306730	2966.515	11205.166	-8238.651	5273.309
Jul-08	812000	32400	28485.4	3914.6	9187.909
Aug-08	117250	452.2333	4724.95	-4272.7167	4915.1923
Oct-09	108000	3888	4408.6	-520.6	4394.5923
Nov-0	268140	10260	9885.388	374.612	4769.2043
Dec-09	284200	10584	10434.64	149.36	4918.5643
Jan-l09	643100	24840	22709.02	2130.98	7049.5443
Feb- 09	976000	35280	34094.2	1185.8	8235.3443
Oct-10	913000	32760	31939.6	820.4	9055.7443
Nov-10	538680	22068	19137.856	2930.144	11985.8883
Dec-10	493440	15300	17590.648	-2290.648	9695.2403
Jan-10	897950	31212	31424.89	-212.89	9482.3503

Feb-10	1037400	33480	36194.08	-2714.08	6768.2703
Mar-10	873000	29484	30571.6	-1087.6	5680.6703
Apr-10	750300	28451.52	26375.26	2076.26	7756.9303
May-10	850000	29016	29785	-769	6987.9303
Oct-11	833000	22140	29203.6	-7063.6	-75.6697
Nov-11	910000	22572	31837	-9265	-9340.6697
Dec-11	358210	16848	12965.782	3882.218	-5458.4517
Jan-11	453580	19836	16227.436	3608.564	-1849.8877
Feb-11	492500	21096	17558.5	3537.5	1687.6123
Mar-11	847640	28566.32	29704.288	-1137.968	549.6443
Apr-11	686400	23544	24189.88	-645.88	-96.2357

Figure 5.18 electrical energy consumption show CUSUM analysis explains in the same principle but electrical energy consumption. CUSUM Analysis is more improvement but the thermal energy consumption is no improvement because the graph is upward more energy consumption and downward gradients show sustained better than expected performance. CUSUM Control Chart of the industry for the year 2008 to 2011E.C.One-sided upper CUSUM verses sample numbers are plotted as red color points and lower CUSUM are plotted as black color points.

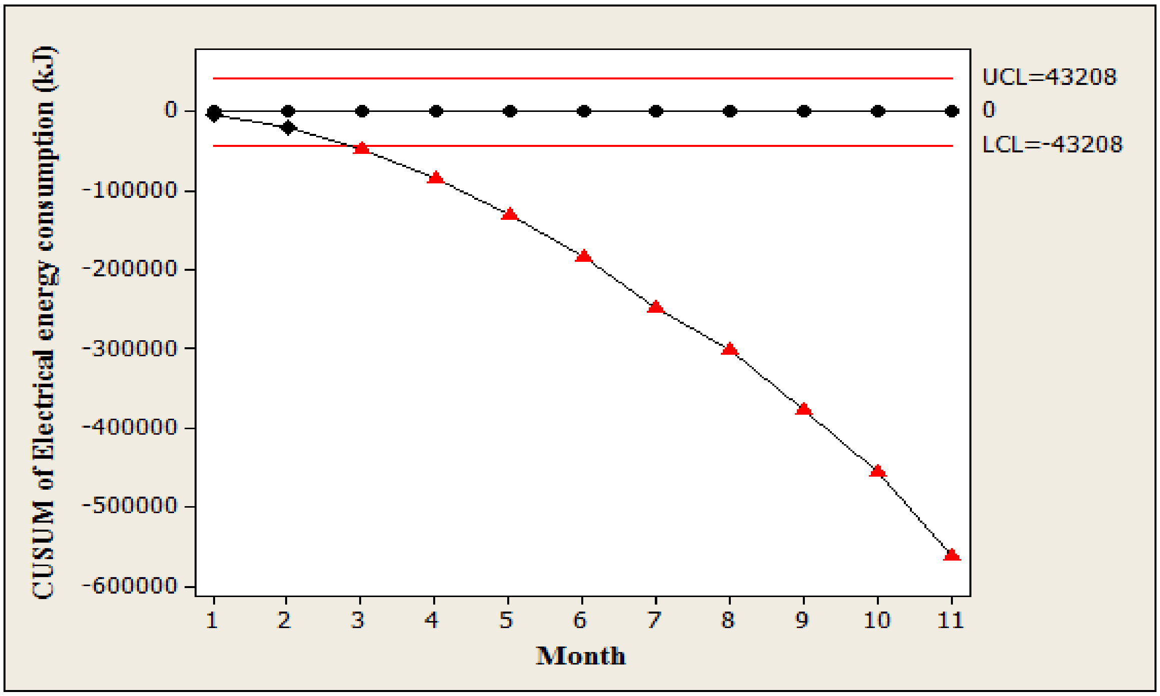

Figure 5.18: The CUSUM Chart of Electrical Energy Consumption

Hence electrical energy consumption of the factory does recognize the problem of wastage such as loss in kiln infiltration air atmospheric, less efficiency of furnace, energy management problem. Electrical energy consumption for the same production about energy consumption trends.

Based on the graph 5.18 number observation (7-10) (see in table 5.11) saving of 1753.8877 kJ/kg (1849.8877-96) kJ/kg has been accumulated in the last 3 months. This represents savings of almost 2 % of energy consumption.

$\frac{1753.8877}{87680.1} \times 100\% = 2\%$

5.4.5 Interpreting both thermal and electrical energy of the CUSUM graph

Both the CUSUM graph reveals changes in energy performance at any month where there is a significant change in the slope of the line. An upward line of regression model indicates energy is more consumed in comparison to baseline model performance, while an upward trending line indicates a higher rate of consumption. The critical points on the CUSUM graph are the changes in the slope of the line. These can be easily seen, and more precisely located by laying straight lines over the more or less constant slope sections, as explained in both the CUSUM graph. It shows that these slope changes occurred in the month.

More specifically in terms of the process being analysis, the graph indicates:

- There have been measures to reduce consumption in electrical energy and thermal energy CUSM analysis.
- The measure Thermal energy consumption had saved 1007.91MJ
- The measure electrical energy consumption had saved 96.23kJ

5.4.6 Identification sources of energy savings

The CUSUM graph indicates when performance changes occurred, and what they achieved in terms of energy saved or wasted. This implies thermal energy wasted energy due to different reasons such as heat loss in moisture, preheating heavy fuel oil is less, infiltration atmosphere kiln, etc. however, electrical energy management is saved we have shown the graph is downward trending the process of the factory.

It does not directly indicate in numerical valve because this paper studies preliminary energy audit not investigated detail energy audit .hence the factory is working for a long period of time so there is no individual parameter. However, further examination of the period of best performance, months November (2009 – 2010) year (target thermal energy process the target of graph indicated does give some further information.Figure 5.19 and 5.20 is the regression line for those months.

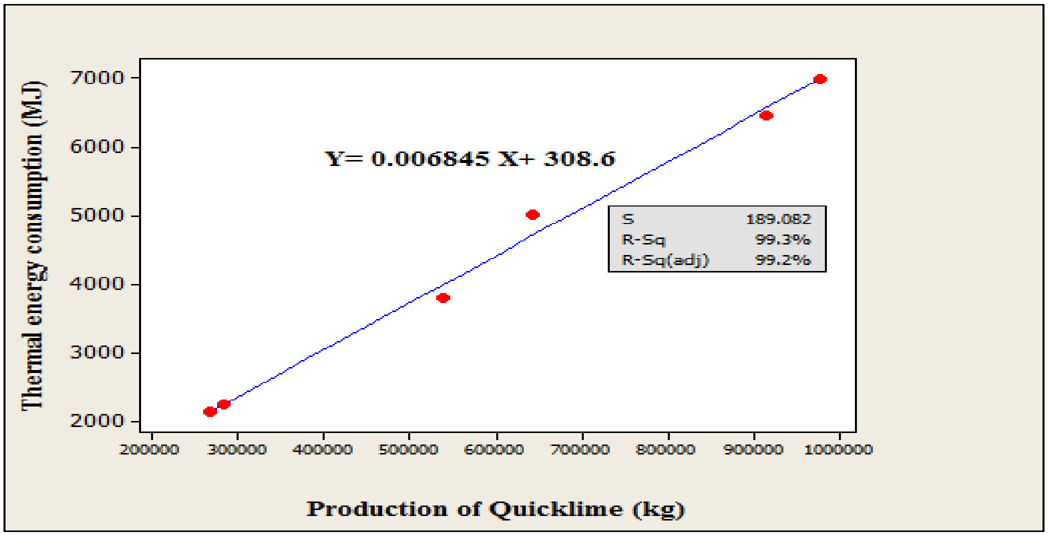

Figure 5.19: Thermal Energy Consumption Regression for Month Nov (2009-2010)

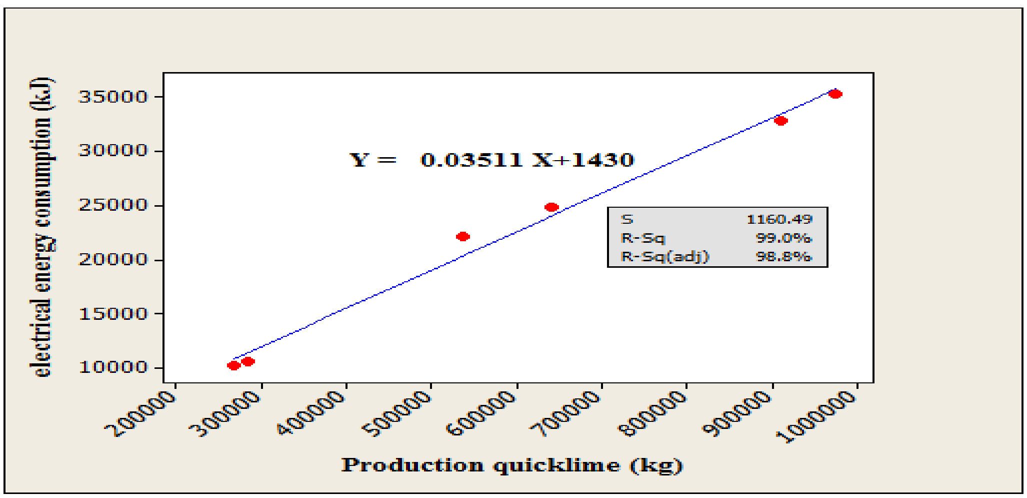

Figure 5.20: Electrical Energy Consumption Regression for the Target Month

Table 5.10: Comparison of target performance period to baseline period

Type of energy	Thermal energy consumption(MJ)			electrical energy consumption(kJ)		
Parameter	Baseline	Target	%improvement	Baseline	Target	%improvement
slope-production associated consumption	0.00652	0.00685	4.82	0.0346	0.03511	1.5
Intercept-production non -associated 9consumption	874.3	308.6	99.96	12170	1430	88.25

This paper is improvement in the factory process cause of change performance or using the reference best period of year production increase and energy consumption decrease so in this reason some production- associated both Thermal energy consumption and electrical energy consumption is 4.82% & 51.5% while the production- not -associated baseload has been reduced by 99.96% and 88.25% respectively that is there has been an improvement in operating efficiency as well as a reduction in baseload waste.

5.5 Setting Energy Performance Targeting for Improving Energy Consumption at ZCSSC

MT & R provide a statistical basis for setting performance targets. The parameter of energy performance model typically quantify incremental and base loads, as seen collected data, and each of these components of the load should be addressed separately. Since an EPM can be defined for any period of historical performance, initial targets are often based on periods of peak performance in the industrial collected data a reasonable target is to sustain the performance of the selected month of the period as defined in the table. 5.20 (comparison of target performance period to baseline period).

The main strategies for setting targets include:

- Eliminating the highest or least efficient of monthly thermal energy performance from the collected data set; in figure 5.9 of monthly production of Quicklime 833000 with 321.5MJ, this would involve deleting the month of that fall above the regression line from the data set and developing a new EPM on what remains. However, the electrical energy performance is not refining with the collected data is corrected.
- Essential best historical performance as the target; in figure thermal energy consumption and electrical energy consumption of regression equation, this would involve selecting only the month of that falls above the regression line and developing a new EPM on this point alone. this is equivalent to selecting the period of the best performance on the CUSUM graph, as indicated above;
- Evaluating the base and incremental loads to the recognized specific action that can be acquired to reduce them and defining a new EPM that adjusts the incremental and based load parameter accordingly.

Whichever method is used, the target setting should be viewed as a continuous improvement strategy to maximize and sustain savings.

5.5.1 Controlling the Energy Performance

Once a target has been set, the challenge is to manage performance to achieve and sustain that performance control charts similar to those used to manage other functions can be constructed from the energy monitoring analysis to control energy performance.

When a reliable predict has been developed, the relationship between the actual consumption and the consumption target by predict can be used to path energy performance. The difference between actual consumption and target consumption can be plotted in a control chart with upper and lower limits set to reflect normal variation in energy consumption. When it deviates above the upper limit is indicates an abnormal event and should aggravate an investigation to identify the cause of poor performance and correct it. If it deviates below the lower limit, this is again unusual and should aggravate an investigation into the sustain performance of the factory.

$$\text{Process Thermal energy (MJ)} = 0.0068X+308.6 \tag{5.16}$$

$$\text{Process electrical energy(kJ)} = 0.03511X+1430 \tag{5.17}$$

Table 5.11: Thermal Energy Consumption Control Chart Calculation for ZCSSC

Billing	Quicklime(kg)	Energy (kJ)(Actual)	predict	variance	CUSUM	Target	Variance
Oct-08	849000	6196.39153	5883.42	312.9715	312.97	6120.01	76.3865
Nov-08	284200	2244.4555	2336.476	-92.0205	220.95	2253.95	-9.4935
Dec- 08	1291000	8740.21132	8659.18	81.03132	301.98	9145.5	-405.28
Feb-08	420000	3101.11762	3189.3	-88.1824	213.8	3183.5	-82.382
Mar-08	641000	8767.28886	4577.18	4190.109	4403.9	4696.25	4071.04
Apr-08	933000	7142.63624	6410.94	731.6962	5135.6	6694.99	447.651
May-08	605000	4409.10572	4351.1	58.00572	5193.6	4449.83	-40.719
Jun-08	306730	2286.31025	2477.96	-191.654	5002	2408.17	-121.86
Jul-08	812000	6142.02654	5651.06	490.9665	5492.9	5866.74	275.287
Aug-08	117250	925.968	1288.03	-362.062	5130.9	1111.18	-185.21
Oct-09	108000	855.776325	1229.94	-374.164	4756.7	1047.86	-192.08
Nov-09	268140	2135.43418	2235.6192	-100.185	4656.5	2144.02	-8.5841
Dec-09	284200	2244.4555	2336.476	-92.0205	4564.5	2253.95	-9.4935
Jan-09	643100	5018.32946	4590.368	427.9615	4992.5	4710.62	307.71
Feb- 09	976000	6997.17315	6680.98	316.1932	5308.7	6989.32	7.85315
Oct-10	913000	6449.53978	6285.34	164.1998	5472.9	6558.09	-108.55
Nov-10	538680	3805.29911	3934.6104	-129.311	5343.5	3995.86	-190.57
Dec-10	493440	3485.71824	3650.5032	-164.785	5178.8	3686.2	-200.48
Jan-10	897950	6343.22486	6190.826	152.3989	5331.2	6455.07	-111.84
Feb-10	1037400	7328.31606	7066.572	261.7441	5592.9	7409.6	-81.287

Mar-10	873000	6166.97566	6034.14	132.8357	5725.7	6284.29	-117.31
Apr-10	750300	5300.20879	5263.584	36.62479	5762.4	5444.4	-144.19
May-10	850000	6004.502	5889.7	114.802	5877.2	6126.85	-122.35
Oct-11	833000	3215.14808	5782.94	-2567.79	3309.4	6010.49	-2795.3
Nov-11	910000	5350.58226	6266.5	-915.918	2393.5	6537.55	-1187
Dec-11	358210	2735.27524	2801.2588	-65.9836	2327.5	2760.55	-25.272
Jan-11	453580	4990.67762	3400.1824	1590.495	3918	3413.36	1577.32
Feb-11	492500	3479.07815	3644.6	-165.522	3752.4	3679.76	-200.68
Mar-11	847640	3961.36237	5874.8792	-1913.52	1838.9	6110.7	-2149.3
Apr-11	686400	2015.46596	4862.292	-2846.83	-1008	5007.01	-2991.5

Figure 5.21 & 5.2 is a control chart, namely a scatter plot of the energy consumption versus the time order in which the objects were produced Run charts provide a useful way of looking at the data to see if (and how) energy consumption and production of quicklime in a different month have been changing over time. We add a horizontal line at the position of the target value if we want to see whether the process is centered on target or straying from target thermal energy consumption stands out as a period of poor performance which needs an investigation to prevent a recurrence, whereas electrical energy consumption stands out as a period of good energy performance, which also advantages investigation.

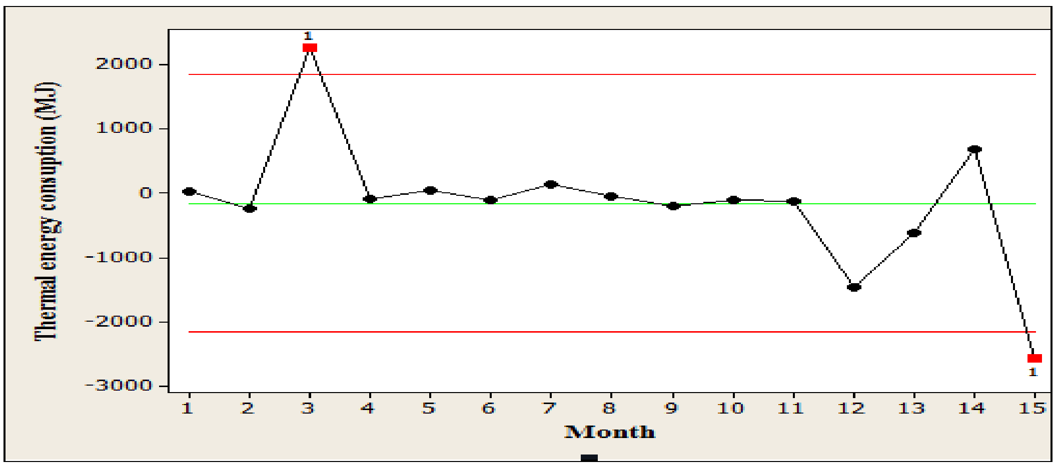

Figure 5.21: Control Chart of Thermal Energy Target for ZCSSC

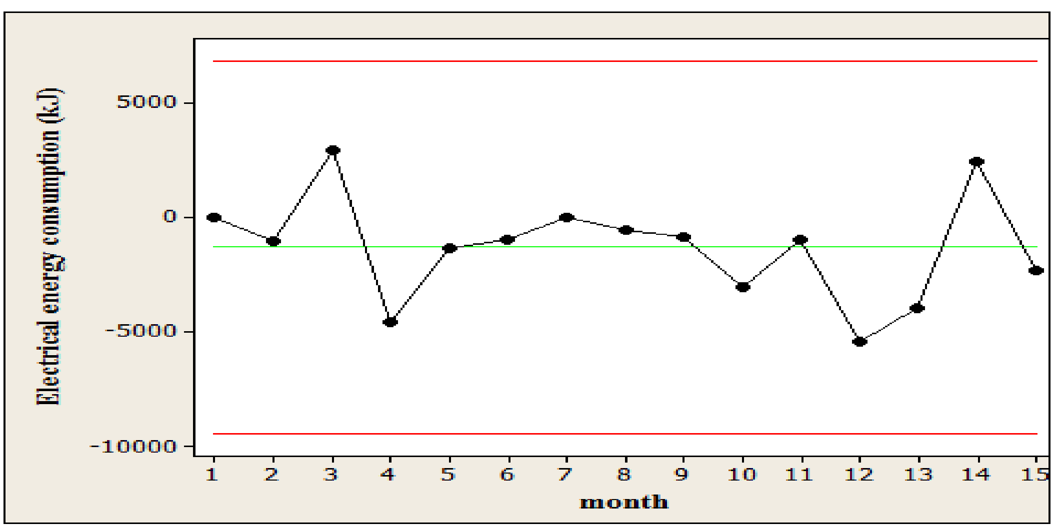

Figure 5.22 Control Chart of Electrical Energy Consumption for ZCSSC

Table 5.12: Electrical Energy Consumption Control Chart Calculation for ZCSSC

Billing	Quicklime(kg)	Energy (kJ)(Actual)	predict	variance	CUSUM	Target	Variance
Oct-08	849000	32076	29750.8	2325.2	2325.2	31238.39	837.61
Nov-08	284200	10584	10434.64	149.36	2474.56	11408.26	-824.262
Dec- 08	1291000	44712	44867.2	-155.2	2319.36	46757.01	-2045.01
Feb-08	420000	16200	15079	1121	3440.36	16176.2	23.8
Mar-08	641000	27000	22637.2	4362.8	7803.16	23935.51	3064.49
Apr-08	933000	36990	32623.6	4366.4	12169.56	34187.63	2802.37
May-08	605000	22748.4	21406	1342.4	13511.96	22671.55	76.85
Jun-08	306730	2966.515	11205.17	-8238.65	5273.309	12199.29	-9232.78
Jul-08	812000	32400	28485.4	3914.6	9187.909	29939.32	2460.68
Aug-08	117250	452.2333	4724.95	-4272.72	4915.192	5546.648	-5094.41
Oct-09	108000	3888	4408.6	-520.6	4394.592	5221.88	-1333.88
Nov-09	268140	10260	9885.388	374.612	4769.204	10844.4	-584.395
Dec-09	284200	10584	10434.64	149.36	4918.564	11408.26	-824.262
Jan-09	643100	24840	22709.02	2130.98	7049.544	24009.24	830.759
Feb- 09	976000	35280	34094.2	1185.8	8235.344	35697.36	-417.36
Oct-10	913000	32760	31939.6	820.4	9055.744	33485.43	-725.43
Nov-10	538680	22068	19137.86	2930.144	11985.89	20343.05	1724.945
Dec-10	493440	15300	17590.65	-2290.65	9695.24	18754.68	-3454.68
Jan-10	897950	31212	31424.89	-212.89	9482.35	32957.02	-1745.02
Feb-10	1037400	33480	36194.08	-2714.08	6768.27	37853.11	-4373.11

Mar-10	873000	29484	30571.6	-1087.6	5680.67	32081.03	-2597.03
Apr-10	750300	28451.52	26375.26	2076.26	7756.93	27773.03	678.487
May-10	850000	29016	29785	-769	6987.93	31273.5	-2257.5
Oct-11	833000	22140	29203.6	-7063.6	-75.6697	30676.63	-8536.63
Nov-11	910000	22572	31837	-9265	-9340.67	33380.1	-10808.1
Dec-11	358210	16848	12965.78	3882.218	-5458.45	14006.75	2841.247
Jan-11	453580	19836	16227.44	3608.564	-1849.89	17355.19	2480.806
Feb-11	492500	21096	17558.5	3537.5	1687.612	18721.68	2374.325
Mar-11	847640	28566.32	29704.29	-1137.97	549.6443	31190.64	-2624.32
Apr-11	686400	23544	24189.88	-645.88	-96.2357	25529.5	-1985.5

5.6 Forecasting of 2012 Fuel Oil, Electricity and Energy Billing /Budgeting

Demand Forecasting refers to the process of predicting future demand for the company's product. The fuel oil, electricity, and energy bill for the factory can be predicted after knowing the production of quicklime demand for future billing years using any forecasting methods, for instance, two months moving average forecasting method.

5.6.1 The use of Two-month Moving Averages in the forecasting in Quicklime factory

Moving Averages is one of the most popular forecasting techniques. This method commends itself because of the simplicity of conception, rendering it more intelligible to users of index numbers, and because of ease of computation, reasonable accuracy, and flexibility to changing conditions. Its adaptability to the measurement of both constant and changing types of energy consumption makes it doubly useful for the analysis of economic series.

The production of quicklime demand for future billing years can be forecasted using the data of previous billing years as using any forecasting methods, for instance, two months moving average forecasting method.

Then the predicted quicklime demand can be used to calculate the fuel oil and electricity demand and energy budging for the future year. The forecast production quicklime p_{t+1} for the upcoming period is the estimate of average level p_t at the end of period *t*.

$$p_{n,m_i} = \frac{p_{n-1,m_i} + p_{n-1,m_{i+1}}}{N} \qquad (5.18)$$

Where: p_{n,m_i} : forecasted quicklime production of year n

p_{n-1,m_i}: previous year actual production of quicklime

N: Number of the month consider for moving an average

m_{i+1}: Every month in the future year

$n-1$: previous year

n: future year

i: number of months in a yeari=1,2,3,…12.

The predicted value of the quicklime production for the first month of the 2012 E.C billing period, using two-month moving average forecasting technique, would be given by

$$p_{2012,m_1} = \frac{p_{2011,m_1} + p_{2011,m_2}}{2}$$

CHAPTER SIX

RESULT AND DISCUSSION

6.1 Technical Feasibility and Economic Analyses of the Proposed ECOs

Zeway Caustic Soda Share Company utilizes both thermal and electric energy to produces quicklime. To show the highlight for energy-saving potential of the factory the average electricity and fuel energy consumption trend of the factory was compared with the energy consumption data of 2009 billing year as shown in Table 6.1 which is a good indicator of the energy and cost-saving potential of the factory.

Table 6.1: Shows the Cost of Energy Consumption of ZCSSC Due to Inefficiently Use

Production	ZCSSC average energy consumption		2009 E.C Selected year plant energy consumption		Energy consumption difference	
Quicklime (ton/year)	kWh/ton quicklime	MJ/ton quicklime	kWh/ton quicklime	MJ/ton quicklime	kWh/ton quicklime	MJ/ton quicklime
4868.430	310183.6	53753.961	280800	52320.217	293836	1433.7435
Cost (Birr/year)	11194726 Birr/year					

The electricity and fuel consumption of ZCSSC has a significant difference with is energy consumption of the 2009 EC billing year. The annual average thermal (fuel) energy consumption intensity of the factory was 53753.961 MJ/ton of quicklime production but the 2009 E.C energy consumption intensity was 52320.217 MJ/ton of lime production. Similarly, the annual average electricity consumption was 310183.6 kWh/ton of production quicklime, but the 2009 E.C electricity consumption intensity was 29383.6 kWh/ton of quicklime. Hence ZCSSC consumes an extra of fuel and electricity of 1433.7435MJ/ton and 29383.6 kWh/ton of quicklime, respectively as compared to 2009E.C. Due to this, the factory paid 11194726 Birr/year extra energy cost for the production of quicklime.

The main energy conservation opportunities for saving electricity consumption identified in the thesis are

- Measuring the power factor of each electric motor
- Replacing old electric motors with new motors
- Installing electric meters
- Studying the electric energy efficiency of the locally fabricated heavy fuel oil preheater reducing the viscosity of the heavy fuel oil and installing electric meter for it.

All of these electric energy conservation opportunities are technically feasible for the factory to execute them which will further reduce its electric energy consumption and electric bill.

The main energy conservation opportunities for saving fuel energy consumption identified in the thesis are

- Reducing thermal energy losses along with the rotary kiln
- Reducing stalk heat loss due to flue gas temperature
- Preheating the combustion air
- Improving the energy efficiency of the furnace

Reduction in heavy fuel oil consumption for operating the rotary kiln operation can be achieved by minimizing various losses occurring in the unit. These losses occur primarily due to the infiltration of air and heat leakage through holes & kiln joints along the 42 m long kiln. These energy conservation opportunities are technically feasible or rather very easy to implement through effective insulation and by minimizing air & moisture leak to the kiln by effectively sealing the holes along the kiln.

The sensible heat loss through due to the flue gas temperature (about 300^{o}C) at the outlet of the kiln can be reduced by installing a heat recovery system. In this regard, attempt was undertaken by the factory to conserve this heat by installing a water heating heat exchanger. But this attempt was not successful due to long distance between the location where hot water is need and the position of the stalk. Hence, installing a heat recovery system currently is not a technically feasible energy conservation opportunity (ECO).

Utilization of preheated combustion air and fuel oil will result in increased costs to the burner system and evaluation needs to be undertaken to determine if the resulting increase inefficiency of the system actually provides an accurate advantage from a cost-savings standpoint. Hence, this energy conservation opportunity (ECO) might be technically feasible if the flues gas is used as energy input for preheating the combustion air.

The energy efficiency of the furnace & rotary kiln was found to be 55.8 and 63.1%, respectively. Furnace efficiency is less than the expected performance of a new furnace oil-fired furnace which is equal to 85-90% [27] and also The kiln performance, when compared with the proposed standard by [28], meets the minimum design standard for kiln efficiency (≥ 75%). The technical feasibility of improving the energy efficiency of the furnace can be carried out by identifying the factors that contribute to the significant drop inefficiency of the furnace. The main causes of inefficiency of the furnace were the energy loss due to:

- Sensible Heat of the Dry Flue Gas
- The presence of H_2 in fuel (loss due to latent heat)
- Holes along with the rotary kiln
- The moisture content of the air,
- The moisture content of the fuel
- Operating the furnace with an oxygen content of 12%.

6.2 Saving Analysis of the technically feasible ECO

According to the results, an increase in combustion efficiency will be the main parameter on the system efficiency by controlling the percentage of oxygen in the combustion chamber. The combustion efficiency of the kiln of furnace was low due to excess air admitted (133.33 %) since the factory operates the furnace with 12% oxygen content of the combustion air. This is less than the 15% recommended value of oxygen. The energy efficiency of the furnace was recalculated using equation (4.43) for 15% oxygen content and the furnace efficiency was found to be about 72%.

As a result, the saved energy can be estimated by using equation (6.1) as follows.

$$\text{Energy saved} = \dot{m}_f \text{ GCV}(\eta_{(comb)15\%} - \eta_{(comb)actual}) \qquad (6.1)$$

Energy saved = 0.072 kg/sec$\times$ $43031\ kJ/kg \times (0.72 - 0.558)$= 501.92kW

Therefore, the energy saved through keeping the oxygen content of combustion air at 15% was found to be 501.92 kW. The equivalent quantity of heavy fuel oil and money saved is 232,729.891liter and 3,414,147.5 Birr per year, respectively.

6.3 Forecasting Thermal and Electrical Energy for Energy Budgeting of 2012 Billing period

The factory can use the energy management modeling program developed in chapter five for budgeting and controlling its 2012 billing period production of quicklime. If the production of quicklime for 2012 billing year is known, both the thermal and electric energy needs of the factor can be found using the regression equations (5.9) & (5.13), respectively for budgeting its 2012 thermal and electrical energy bills. The production of quicklime for 2012 billing year can be forecasting using two-month moving average forecasting method (equation 5.19) or any other method to manage its next year's energy utilization and the corresponding budget.

6.3.1 Two Months Moving Average Forecasting Quicklime production For 2012 E.C

The quicklime production of the factory 2012 EC can be forecasted based on the 2011 billing year production of the factory using the two months moving average forecasting technique (equation 5.18 or 5.19). Using equation 5.19, the 2012 quicklime production of the factory was forecasted as shown in Table 6.2 and plotted in Figure 6.1.

Table 6.2: Forecasting Production of Quicklime for 2012 E.C

Month	2011 production quicklime (kg)	Predict (2012)quicklime production (kg)
m_1	833000	76586.36
m_2	910000	127453.4
m_3	358210	65155.56
m_4	453580	11888.32
m_5	492500	82873.3
m_6	847640	94361.54
m_7	686400	48009.36

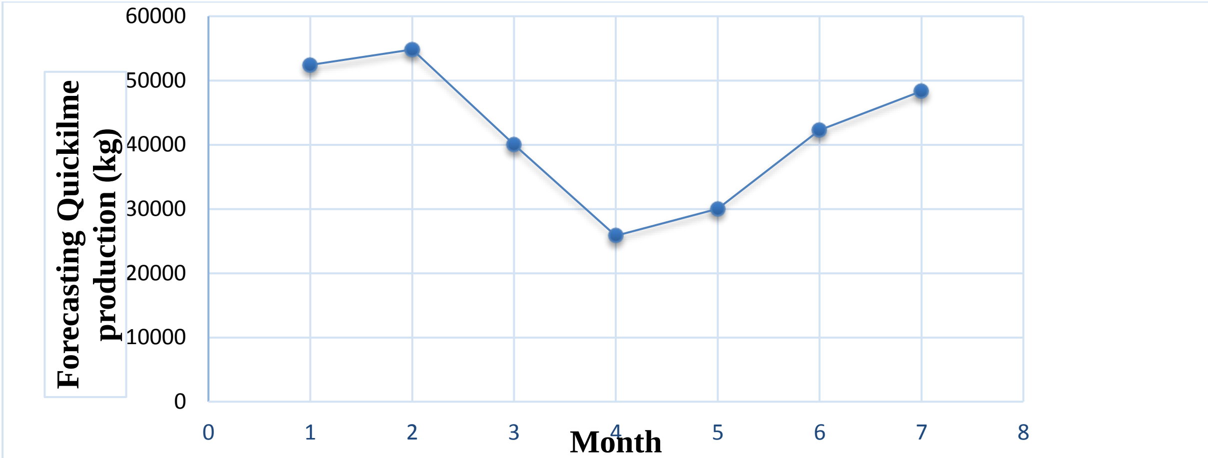

Figure 6.1: Forecasting Demand for Quicklime Production for 2012 E.C

6.3.2 Two Months Moving Average Forecasting Thermal and electrical Energy for 2012

Predicting thermal energy consumption, electrical energy consumption, energy intensity, and corresponding energy bill is important for managing the energy expenses and profit of the factory. Using the predicted data of quicklime production for 2012 indicated in Table 6.2 or Figure 6.1, the thermal and electric energy required for 2012 billing period are calculated using (5.9) and (5.18), respectively. The thermal energy required for producing quicklime in 2012 is shown in Table 6.3 and Figure 6.2. Similarly, the electric energy required for producing quicklime in 2012 is shown in Table 6.3 and Figure 6.3.

Table 6.3: Forecasted Thermal and Electric Energy Consumption in 2012 E.C

Month	Actual production quicklime (kg)	Predict production quicklime (kg)	Forecasting Thermal energy consumption (MJ)	Forecasting electrical energy consumption ((kJ)
m_1	833000	833000	52430.94	29203.6
m_2	910000	871500	54828.72	30520.3
m_3	358210	634105	40043.76	22401.4
m_4	453580	405895	25830.84	14596.6
m_5	492500	473040	30012.63	16893
m_6	847640	670070	42283.66	23631.4
m_7	686400	767020	48321.71	26947.1

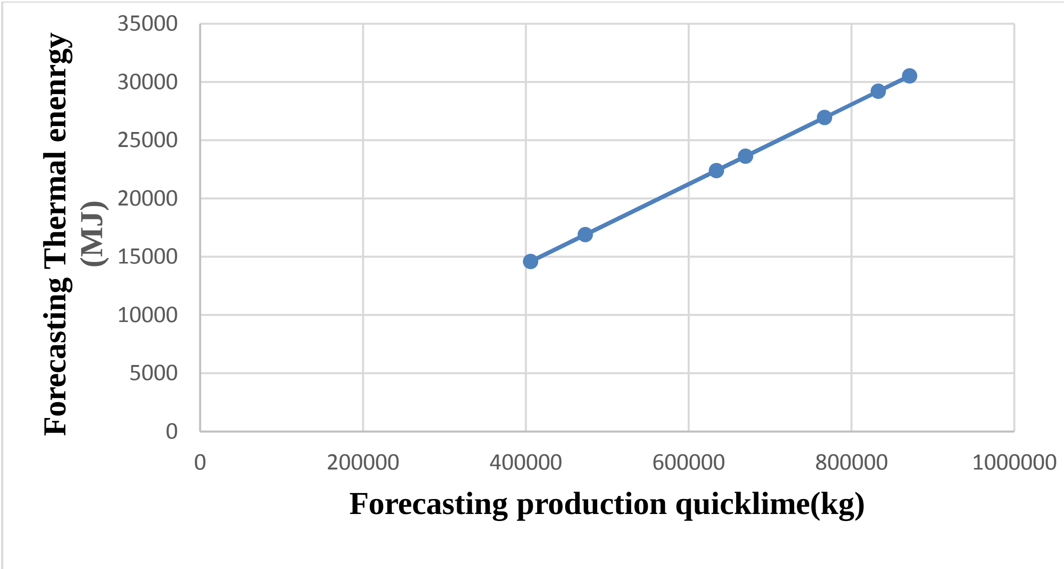

Figure 6.2: Relating Forecasting Thermal Energy Consumption and Quicklime Production

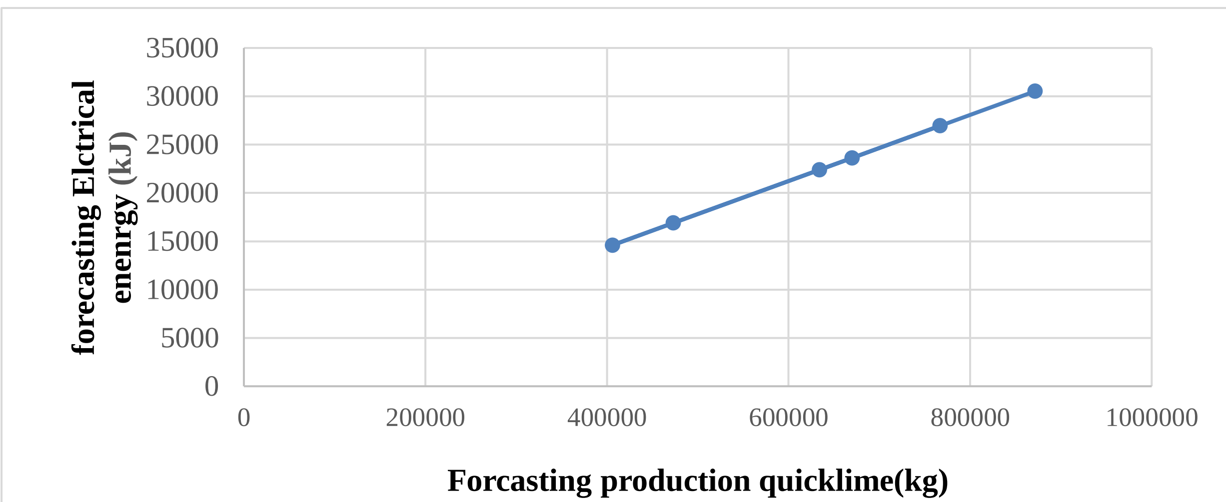

Figure 6.3: Relating Forecasting Thermal Energy Consumption and Quicklime Production

6.3.3 Two Months Moving Average Forecasted Fuel Oil quantity and Electricity Consumption for 2012 E.C

The forecasted thermal energy in terms of heavy fuel oil quantity and electricity in kW for 2012 are shown in Table 6.4 and also in Figure 6.4 and Figure 6.5. These data are needed to estimate the fuel oil and electricity consumption energy bill for 2012.

Table 6.4: Forecasted Heavy Fuel Oil Quantity and Electrical Energy Consumption in 2012 E.C

Month	Actual furnace oil consumption in (liter)	Forecasting of fuel oil consumption	Actual Electric consumption (kWh)	Forecasting electric consumption (kWh)
m_1	76586.36	76586.36	61500	61500
m_2	127453.42	102019.9	62700	62100
m_3	65155.56	96304.49	46800	54750
m_4	11888.32	38521.94	55100	50950
m_5	82873.3	47380.81	58600	56850
m_6	94361.54	88617.42	81900	70250
m_7	48009.36	71185.45	65400	73650
Total	506327.9	520616.4	432000	430050

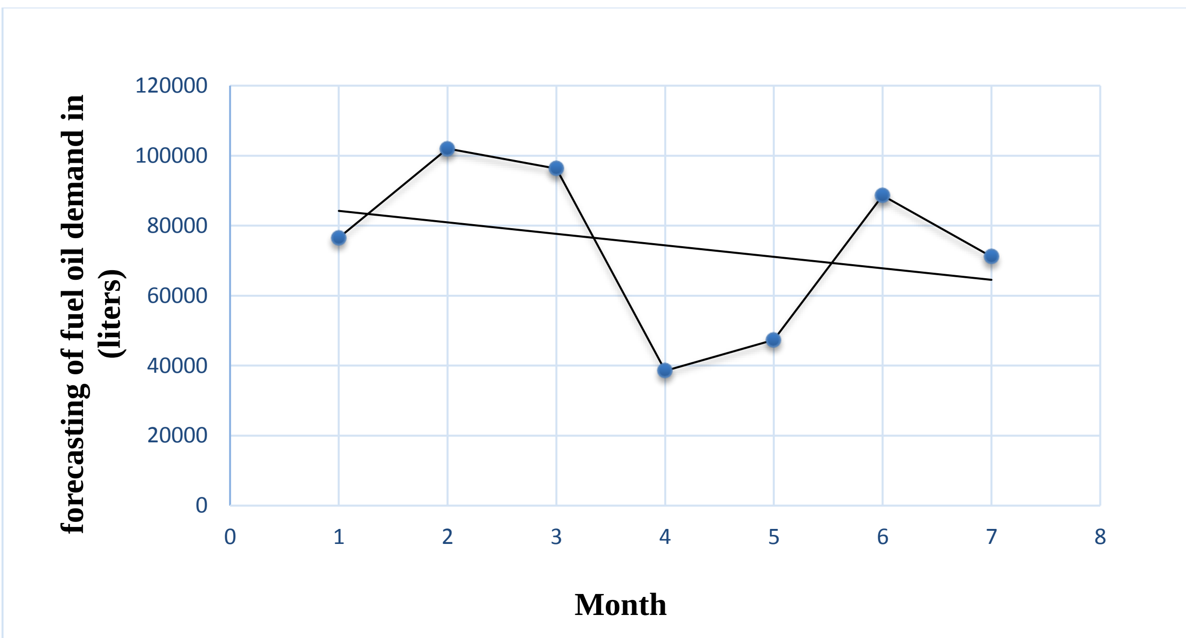

Figure 6.4: Forecasting Fuel Oil Consumption for 2012 E.C

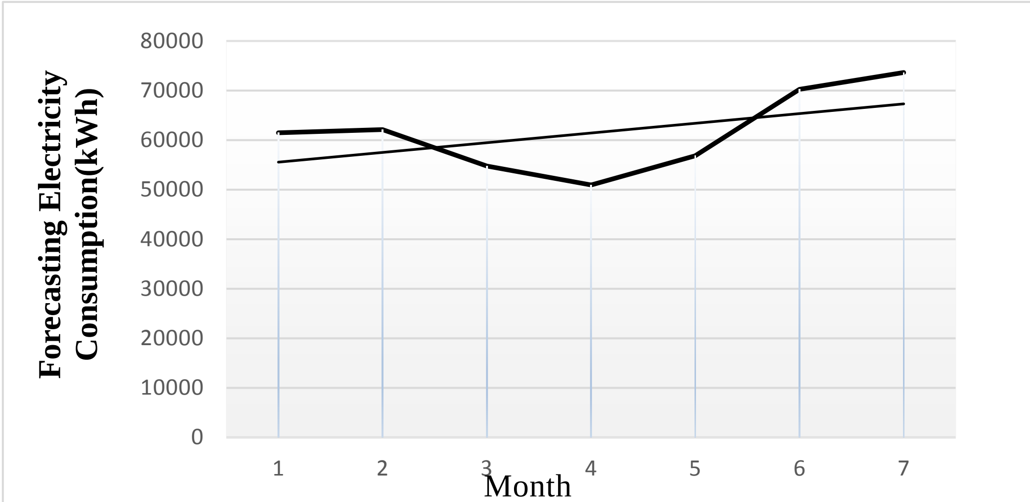

Figure 6.5: Forecasting Electricity Consumption for 2012 E.C

6.3.4 Two Months Moving Average Forecasting Both Thermal and Electrical energy intensity demand for 2012 E.C

The forecasted thermal energy and electricity intensity for 2012 is shown in Table 6.5 and also in Figure 6.6 and Figure 6.7. These data are needed to estimate the fuel oil and electricity consumption energy bill for 2012.

Table 6.5: Forecasting of Thermal and Electrical Intensity Consumption for 2012 E.C

Month	Predict production quicklime (2012E.C)(kg)	Forecasting of furnace oil consumption in (liters)	Forecasting thermal Energy intensity (MJ)	Forecasting electric consumption (kWh)	Forecasting electrical Energy intensity(kJ)
m_1	833000	76586.36	3859721.6	61500	265.7863
m_2	871500	102019.9	4914361	62100	256.5232
m_3	634105	96304.49	6375803.3	54750	310.8318
m_4	405895	38521.94	3984226.3	50950	451.8903
m_5	473040	47380.81	4204885.4	56850	432.6484
m_6	670070	88617.42	5551987.5	70250	377.4233
m_7	767020	71185.45	3896135.9	73650	345.6755
Total	4654630	520616.4	32787121	430050	2440.779

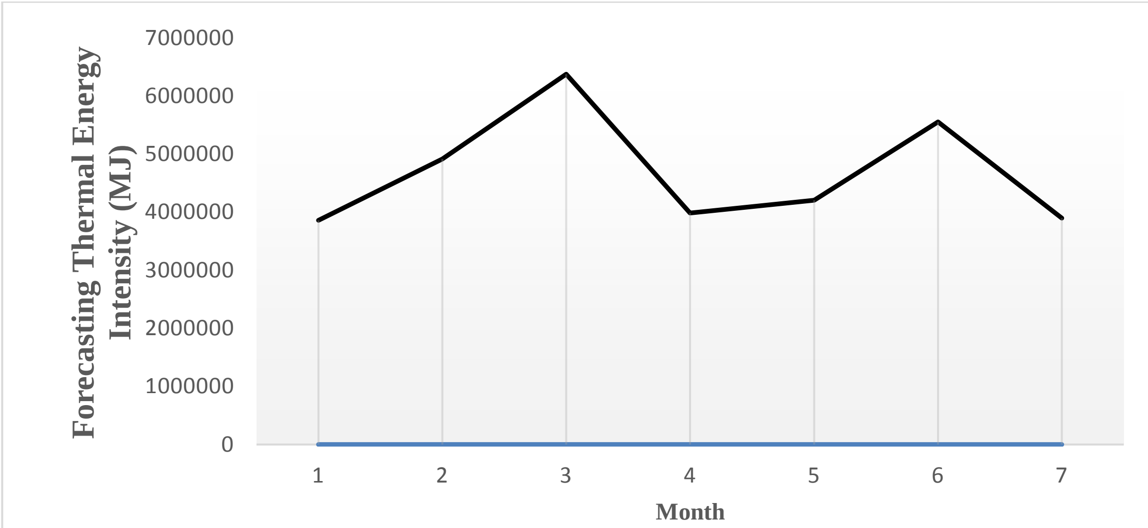

Figure 6.6: Forecasting Thermal Energy Intensity (MJ) for 2012 E.C

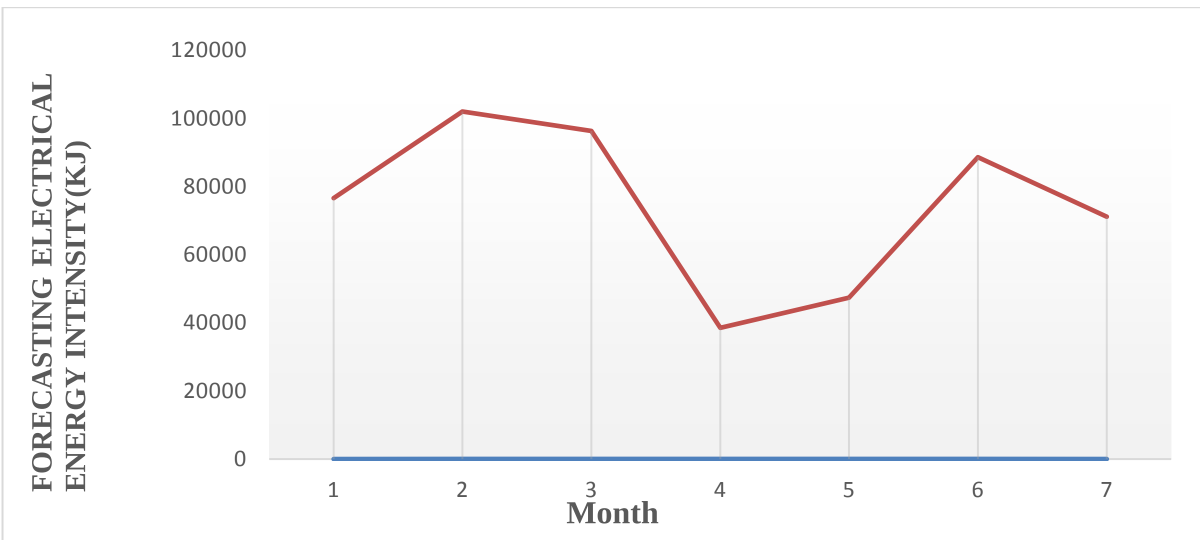

Figure 6.7: Forecasting Electrical Energy Intensity (MJ) for 2012 E.C

6.3.5 Two Months Moving Average Forecasted Thermal and Electrical Energy Cost or budget for 2012 E.C

The forecasted thermal energy and electricity cost or budget for 2012 calculated using equation (5.2) & (5.12), respectively based on the forecasted fuel oil quantity and electricity is shown in Table 6.6 and also in Figure 6.8 and Figure 6.9. These cost data are important for the factory to evaluate its profit and operation cost for the 2012 operation year by thoroughly comparing its sell with the production cost of quicklime.

Table 6.6: Forecasting Fuel Oil and Electricity Cost Analysis for 2012 E.C

Month	Forecasting furnace oil (liters)	Forecasting Fuel Oil Cost(birr/liters)	Forecasting electric consumption (kWh)	Electricity Energy Cost (birr/kWh)
m_1	76586.36	1123522	61500	39975
m_2	102019.9	1496632	62100	40365
m_3	96304.49	1412787	54750	35587.5
m_4	38521.94	565116.9	50950	33117.5
m_5	47380.81	695076.5	56850	36952.5
m_6	88617.42	1300018	70250	45662.5
m_7	71185.45	1044291	73650	47872.5
Total	520616.4	7637442	430050	279532.5

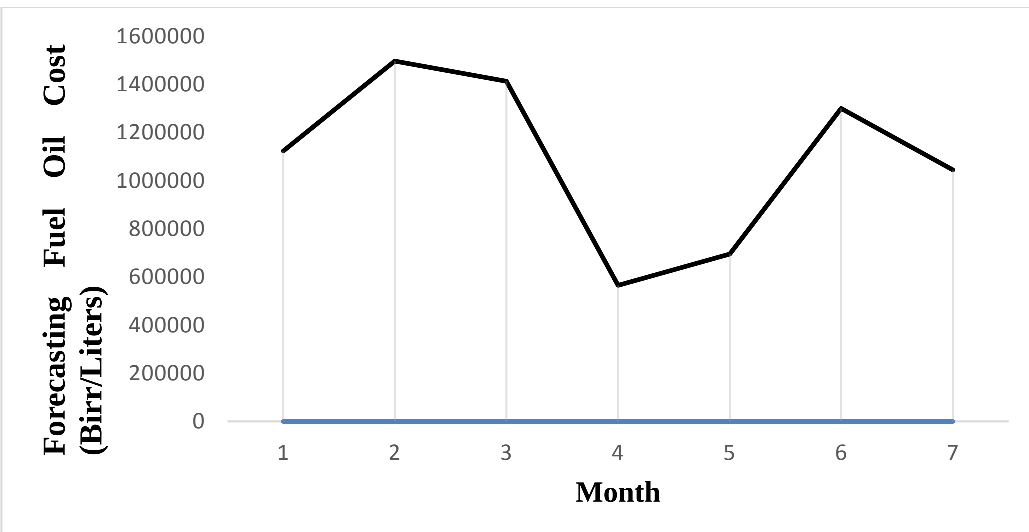

Figure 6.8: Forecasting Fuel Oil Cost Analysis for 2012 E.C

Generally, the forecasted annual average thermal (fuel) and electricity energy consumption intensity of the factory is 32787121 MJ/ton of quicklime & 2440.779 kWh/ton of quicklime production. The forecasted fuel oil & electricity cost or energy budget of the factory for 2012 are 7,637,442 Birr/liters and 279533 Birr/kWh. Therefore, total forecasted energy budget of the factory in 2012 E.C is 7,916,975 Birr/year.

CHAPTER SEVEN

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

7.1 Conclusions

This thesis studied the energy utilization of Zeway Caustic Soda share Company quicklime production system by analyzing the heavy fuel combustion and its management of thermal energy and electricity utilization performance using four years energy utilization data.

The paper also investigated the thermal and electric energy utilization intensity and developed regression equations that can be used for monitoring, targeting and reporting the past, current and future energy utilization of the factory using cumulative sum (CUSUM) energy management program (EMP).

From the performance analysis /study result, the final value examines the performance of the process in terms of production quicklime and consumption energy.

The specific energy of the factory was determined using different data collected by inspection through the walk, interviewing of the factory workers, referring to the nameplate of the major energy-consuming systems, talk about to the factory data record books and catalogs, and direct measurement using movable measuring instruments. In the chapter the major Energy Conservation Measures are recommended with, particularly saved energy, the cost of saved energy.

The standard chemical reaction of furnace oil burning on a mass basis was used to investigate the theoretical air-fuel ratio and the constituents of the fuel chemistry & the dry flue gas.

The efficiency of the two major energy-consuming systems of the factory that is the furnace and kiln was also calculated by a direct and indirect method. In addition some energy conservation opportunities (ECOs) were identified during preliminary walk-through energy audit inspection and from the combustion performance of the furnace.

The main finding of the thesis was

- The combustion efficiency and
- The theoretical air-fuel ratio was found to be 11.13 kg/kg of fuel.
- The energy efficiency of the furnace & rotary kiln were found to be 55.8 and 63.1%, respectively.
- The factory operates the furnace with an oxygen content of 12%.

The operating oxygen percent in the fuel gas (12%) which is less than the recommended 15% oxygen content for fuel-fired furnaces. This was taken as the main cause for energy conservation opportunities (ECOs) for improving the furnace efficiency which also is easily implemented. The energy efficiency of the furnace for 15% oxygen content was calculated and found to be 72%. Therefore, the energy saved through keeping the oxygen content of combustion air at 15% was found to be 501.92 kW. The equivalent quantity of heavy fuel oil and money that could be saved is 232,729.891liter and 3,414,147.5 Birr per year, respectively

The paper also investigated the thermal and electric energy utilization intensity and developed regression equations that can be used for monitoring, targeting and reporting the past, current and future energy utilization of the factory using cumulative sum (CUSUM) which is a technique of energy management program (EMP). This thesis has also presented forecasted the values of the next year (2012 EC) quicklime production using two-month moving average method. The forecasted value of the quicklime production of the 2012EC operation of the factory was used to estimate thermal and electric energy requirement and energy bill that will help the factory to manage its 2012 EC energy utilization using the energy management modeling programs developed in the thesis. Based on the finding of the CUSUM energy management technique consumption of fuel oil energy was found to be increasing from year to year but the electric energy consumption was decreasing. Thus, the factory has worked more on improving its fuel energy utilization to reduces its fuel energy cost and be profitable.

7.2 Recommendations

- The factory must operate the furnace at 15% oxygen content to improve the furnace efficiency and reduce fuel energy wastage.
- The factory must replace the old motors to reduce its electric energy consumption further.
- The factory should implement the energy conservation measures discussed in this thesis and monitor the success of the energy conservation measures by applying for the CUSUM energy management program

7.3 Suggestions for Future Work

The electrical energy conversion efficiency of the locally fabricated heavy fuel oil preheater that thins the heavy fuel oil or reducing the viscosity of the heavy fuel oil should be studied.

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APPENDIX A:

Monthly Factory Energy, Material, and Product Data

Monthly Factory Energy, Material, and Product Data 2008

Billing period (E.C)	Total production of quicklime [kg]	monthly of Fuel consumption in (liter)	Monthly electric consumption(kwh)
October	849000	147601	89100
November	284200	53464	29400
December	1291000	208196	124200
February	420000	738701	45000
March	641000	208841	75000
April	933000	170141	102750
May	605000	105027	63190
Jun	306730	54461	3300
July	812000	146306	90000
August	117250	22057	3150

Monthly Factory Energy, Material, and Product Data 2009

Billing period (E.C)	Total production of quicklime [kg]	monthly of Fuel consumption in (liter)	Monthly electric consumption kwh
October	108000	20385	10800
November	268140	50867.06	28500
December	284200	53464	29400
January	643100	119539	69000
February	976000	166676	98000

Monthly Factory Energy, Material, and Product Data 2010

Billing period (E.C)	Total production of quicklime [kg]	monthly of Fuel consumption in (liter)	Monthly electric consumption kWh
October	913000	153631.112	91000
November	538680	90644.0388	61300
December	493440	83031.47	42500
January	897950	151098.64	86700
February	1037400	174563.982	93000
March	873000	146900.3	81900
April	750300	126253.5	79032
May	850000	143030.1	80600

Monthly Factory Energy, Material, and Product Data 2011

Billing period (E.C)	Total production of quicklime [kg]	monthly of furnace oil consumption in (liter)	Monthly electric consumption
October	833000	76586.36	61500
November	910000	127453.42	62700
December	358210	65155.56	46800
January	453580	11888.32	55100
February	492500	82873.3	58600
March	847640	94361.54	81900
April	686400	48009.36	65400

APPENDIX B:

Unit Conservation

Parameter	conservation	Unit
Calorific valve	BTU/LB	2.326KJ/kg
Fuel	Liter/hr.	0.92kg/hr.
Energy	kJ/sec	kWh
Fuel	liter	0.001m3
Specific heat	Kcal/kg℃	4.188kJ/kg℃

APPENDIX C:

List of Measuring Instruments Used

1. Anemometer
2. Caliper
3. Meter
4. Pyrometer and Beam balance

APPENDIX D:

Elemental Analysis of Furnace oil

Date: June 15, 2019

Number of Samples: 1

Analysis: Elemental analysis: CHNS

Device: EA 1112 Flash CHNS/O- analyzer

Conditions: Carrier gas flow rate of 120 ml/min, the reference flow rate of 100 ml/min, oxygen flow rate 250 ml/min. furnace temperature of 900 °C and oven temperature of 75 °C.

Calibration: 6 calibration points for every component. The sample was run in duplicate and the average values are to be taken.

Elemental analysis Proximate analysis of Heavy fuel oil(Mazut

Name	Sample Code	N(%)	C (%)	H (%)	S (%)
Eskedar	Oil	2.884	84.904	2.104	1.561
Eskedar	Oil	2.208	88.756	1.865	0.987

Proximate analysis of Heavy fuel oil (Mazut)

name	sample type	mass curiciabel	weight of sample	weight of curiciabel +sampel	Test 1(weight)	Test 2(weight)	%
moisture	Oil	39.16	2.39	41.55	39.39	2.16	90.38
Ash	oil	42.4	2.39	44.94	42.55	0.15	6.28

APPENDIX E:

Data Used in the Energy Efficiency Analyses of the Limekiln and Furnace Efficiency

Parameter of efficiency calculation

Time	Fuel Temperatures	Oil quantity	O2 content (%)	Temperatures of furnace of kiln ()	Raw material limestone pebble (kg)	% limestone pebble	% calcium oxide
07	108	220	12	900	81.5	Average	Average
08	105	220	12	900	80.5	93	84
09	106	220	12	900	79		
10	107	220	12	900	81.2		
11	108	280	12	900	60.4		
12	109	290	12	900	60.1		
13	109	220	12	890	82		
14	110	260	12	890	81.5		
15	114	280	12	920	79		
16	111	280	12	920	78		
17	110	270	12	910	80		
18	111	280	12	910	80.3		
19	110	300	12	900	79.3		
20	110	260	12	900	86.8		

ቀን	የፈረቃ ጊዜ	የነዳጅ መነሻ	የነዳጅ መድረሻ	የነዳጅ መጠን በፈረቃ	የነዳጅ መጠን በቶን	ተረኛ አናሊስቶች	ተረኛ ኦፐሬተሮች
8-2012	6:00-14:00	37110	638726	1616	157.04	አለማ የሁና ቀ፡ዲበኩሉ	ደሳለኝ ተስፋዬ
	14:00-22:00	638726	639804	10778	117.04	ወጫጎና	አቶ፡ፈለቀ
	22:00-06:00	639804	641536	1732	112.61	በቀለ	ጥጋቡ