University of Nairobi

School of Engineering

Analysis of Energy Cost Savings by Substituting HFO with Biomass for a Pozzolana Dryer

A Case Study of Bamburi Cement, Athi River

By

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DECLARATION

Declaration by the Student

I **Veronica Ngunzi** declare that this report is my original work, and except where acknowledgements and references are made to previous work, the work has not been submitted for examination in any other University.

Signature.........................Date...................

Approval by supervisors

I confirm that the study was carried out under my supervision and has been submitted for examination with my approval as University supervisor.

Prof. F.M. Luti: Signature................................. Date..............................

Prof. B. O .Odera: Signature................................ Date..............................

DEDICATION

To My Late Dad, Leonard Emmanuel Ngunzi,

Thank you for your sacrifice, support and inspiration in my life. You legacy shall live on. Rest in peace Dad.

ACKNOWLEDGEMENT

First is my sincere gratitude to the Almighty God for the gift of life, good health, resources and everything else throughout the course. This work would not have been a success without the scholarly assistance, guidance, patience and self-sacrifice of my supervisors Prof. F.M. Luti and Prof. B. O .Odera and the Department of Mechanical and Manufacturing University of Nairobi for their supervision and assessment.

I equally place on record my appreciation to all my classmates and friends for their support and invaluable contributions throughout the course. I also acknowledge and thank Bamburi cement Athi River especially David Nteere and David Lumumba for their support during my data collection. To all of you, God bless.

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ABSTRACT

Pozzolana drying increases the energy per tonne of cement produced. This is due to the energy required to reduce the moisture content to about two to three percent. This energy is obtained from heavy fuel oil. High and fluctuating cost of heavy fuel oil calls for a solution which has been sought through substitution of heavy fuel oil with biomass. This project investigates how much savings are gained by the substitution and what percentage substitution is economically viable. This research was guided by three objectives, namely: studying the existing system and establishing the energy situation of the existing dryer and the auxiliary system to handle biomass, comparing a projected substitution scenario with actual substitution and carrying out the economic analysis of the new system in order decide on the viability of the project. From the research findings of the projected substitution cost, the total energy cost was reducing with increase in percentage AF substitution and HFO cost was also was reducing with an increase in percentage AF substitution. Again AF cost was increasing with increase in percentage AF substitution and cost savings were increasing with increase in percentage AF substitution. The coefficient of correlation (R^2) of total energy cost, cost of HFO, and cost of AF and savings with a percentage of AF substitution was 1. These graphs were straight line graphs because the forecast was ideal. However, from real substitution carried out, the total energy cost and HFO cost were reducing with an increase in percentage AF substitution. Again AF cost and savings were increasing with increase in percentage AF substitution. The coefficient of correlation (R^2) of total energy cost, HFO cost, AF cost and savings with the percentage AF substitution were 0.5422, 0.7096, 0.9645 and 0.6288 respectively. These graphs were not smooth graphs because the forecast was real and affected by clogging of the drier by rice husks. From the economic analysis the cost benefit analysis a positive net present value of 67,409,040.84 was realized which was an indicator that the substitution was worthwhile. The IRR was calculated to be 4.10 %. Again the simple payback period was 12 days and return on investment was 29.72%. Using these four techniques of capital budgeting, i.e. NPV, IRR, the simple payback period and ROI the investment was worthwhile to undertake. Further on economic analysis substitution effect and substitution equilibria was carried out., On the substitution effect, there was gradual cost drop of the energy used to dry pozzolana from 357491491.33 Kenya shillings with increasing percentage AF substituted to 106,269975.03 Kenya shillings when HFO is completely substituted by AF. Again two points of equilibrium were discovered. Equilibrium 1 was the point where the total energy cost was equal to AF cost. This was realized at 100% where the total energy was derived from the AF. Equilibrium 2 was the point where the HFO cost was equal to AF cost. This was at 77%. The savings curve also cuts the curve of HFO cost and total cost at 58% and 70% respectively. This is because of the low cost AF used. Although the cost of energy and total cost of HFO reduced with an increase in percentage substitution while savings increase with increase in percentage substitution further research is required to investigate other economic dynamics that may affect the substitution such as, AF fuel availability and efficiency of the system.

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NOMENCLATURE

€	Euro
AF	Alternative Fuel
bgt	Budget
CO	Carbon Monoxide
CO_2	Carbon Dioxide
GHG	Green House Gas
GJ	Giga Joule
HFO	Heavy Fuel Oil
HGG	Hot Gas Generator
IPCC	Intergovernmental Panel on Climate Change
kWH	Kilowatt Hour
MJ	Mega Joule
MRFs	Material Recovery Facilities
MtC	Metric tons of carbon
NGP	Nairobi Grinding Plant
NO_x	Nitrogen Oxides
ppm	Parts per Million
SO_2	Sulphur Dioxide
Tpa	Tonnes per Annum
USA	United States of America
YTD	Year to Date

CHAPTER ONE: INTRODUCTION

1.0 Background of the Study

The use of biomass instead of fossil fuels is gaining acceptance as a cost effective form of renewable energy use. This is happening at a time when the prices of fossil fuels continue to increase as compared to that of biomass. Beside the lower costs, biomass fuel results in lower emissions and residues. According to Kurchania et al. (2006), biomass energy or ‘‘bio-energy’’ includes any solid, liquid or gaseous fuel, or any electric power or useful chemical product derived from organic matter, whether directly from plants or indirectly from plant-derived industrial, commercial or urban wastes, or agricultural and forestry residues. Thus bio-energy can be derived from a wide range of raw materials and produced in a variety of ways. Because of the wide range of potential feed stocks and the variety of technologies to produce them and process them, bio-energy is usually considered as a series of many different feedstock/technology combinations. Although the heating industry has been dominated for the past five decades by gas, oil, and electric models, the growing trend for "green" alternatives is boosting sales in the biomass business providing many with a new view of options available on the market today.

The production of cement is an energy-intensive process. The typical energy consumption of a modern cement plant is about 110-120 kWh per ton of produced cement (Alsop, 2001). While the continuously increasing world's cement demand grows, the plant's energy demand grows as well. Grinding of cement clinker is also an energy intensive operation that plays a significant role in the overall carbon footprint of the cement industry. The energy consumption in the cement mills contributes roughly 50 kg CO_2 emissions per tonne to the overall greenhouse gas emissions of the industry (MIT – Research, 2011). The most energy-consuming cement manufacturing process is finish grinding, drawing, on average 40%, of the total energy required to produce a ton of cement (Alsop, 2001).

Pozzolana is one of the main components of pozzolanic cement accounting for 35% of the mass of cement. This pozzolana has to be dried before inter-grinding with clinker in order to maintain cement to clinker ratio and to maintain higher grinding efficiency. Bamburi NGP uses a couple of dryers which are traditionally equipped with hot gas generators (HGG) fired by either diesel oil or heavy fuel oil (HFO). The price gap between the fossil fuels in use today to dry these materials and the possible price of the biomass which is in the range 8 - 10€/GJ (Bamburi cement annual report, 2012), there is a clear interest to study the possibility of converting the existing HGGs to use biomass. In order to reduce cost of fuel for drying pozzolana and dependence on and the use of fossil fuels, Bamburi-Lafarge company cement is striving as far as possible to substitute them with alternative fuels especially from biomass. The term fuel substitution implies introduction of new energy sources that do not replace, but supplement, existing fuel types. Even when new sources of fuel are introduced, traditional fuels continue to be important (Bamburi cement annual report, 2012).

Cement is the key material in building and construction industry, noticeable by the rapidly increasing world production. Simultaneously, the cement producing industry is obligated to constantly modernize and improve the process technology to meet on the one hand the increasing governmental constrains on environmental impact and to increase the profitability by increasing the production capacity and reducing the energy consumption. Cement production remains a high energy consuming and polluting sector in the industrial world. Special focus has been laid on the high energy consumption (thermal and electrical energy) involved in cement production, since fuel costs contribute significantly to the manufacturing costs. One possible solution to reduce the fuel costs is by introducing alternative fuels, such as household waste, biomass, plastics, rubber, tyres, paper waste, sewage sludge, waste oil and solvents, into cement production (Giddings *et al*, 2000).

Drying is a complex operation involving transient transfer of heat and mass along with several other processes, such as physical or chemical transformations, which, in turn, may cause changes in product quality as well as the mechanisms of heat and mass transfer. Physical changes that may occur include: shrinkage, puffing, crystallization and glass transitions. In some cases, desirable or undesirable chemical or biochemical reactions may occur leading to changes in colour, texture, odor or other properties of the solid product. Drying occurs by effecting vaporization of the liquid by supplying heat to the wet feed stock. Heat may be supplied by convection (direct dryers) or by conduction (conduct or indirect dryers), radiation or volumetrically by placing the wet material in microwave. Drying of various feed stocks is needed for one or several of the following reasons: need for easy-to-handle free-flowing solids, preservation and storage, reduction in cost of transportation, achieving desired quality of product, etc. In many processes, improper drying may lead to irreversible damage to product quality and hence a non-saleable product (Mujumdar, 2006).

In the cement industry, when using dry process to manufacture cement, all sorts of hydrous materials, such as raw materials and additives should be dried. All of these need the rotary dryer to reduce moisture content. The moisture in the materials has a great effect on the output of grinding machine, the production quality and the operation of grinding mill. If the materials have more moisture, the humidity of the grinding machinery is above the average, fine materials will adhere to grinding body, lining board and shifting board, resulting in grinding efficiency decrease. Moreover, the more moisture in material will inevitably make grinding mill working conditions worse, and then bring about more difficulty in its operation and quality control. In addition, moisture affects the mix proportion of materials fed into the grinding mill thus the grinding production quality affected. (http://www.zd-dryer.com/Technology/121.html, 2013).

1.1Nairobi Grinding Plant

The dryer to be studied is at the Nairobi grinding plant (NGP) in Athi-river about 26km from Nairobi along the old Mombasa road and next to the Namanga junction. This plant is part of the Bamburi cement Company which belongs to the Lafarge group (the world largest manufacturer of building materials). On average the plant produces 100 000 tonnes of cement consuming about 150 000 litres of HFO per month. The HFO is used in drying pozzolana before inter-grinding with the clinker. Heat consumption by the dryer depends on the amount of water in the pozzolana as shown in figure 1.1.The amount of water in the pozzolana also depends on seasons and the source as shown in figure 1.2.

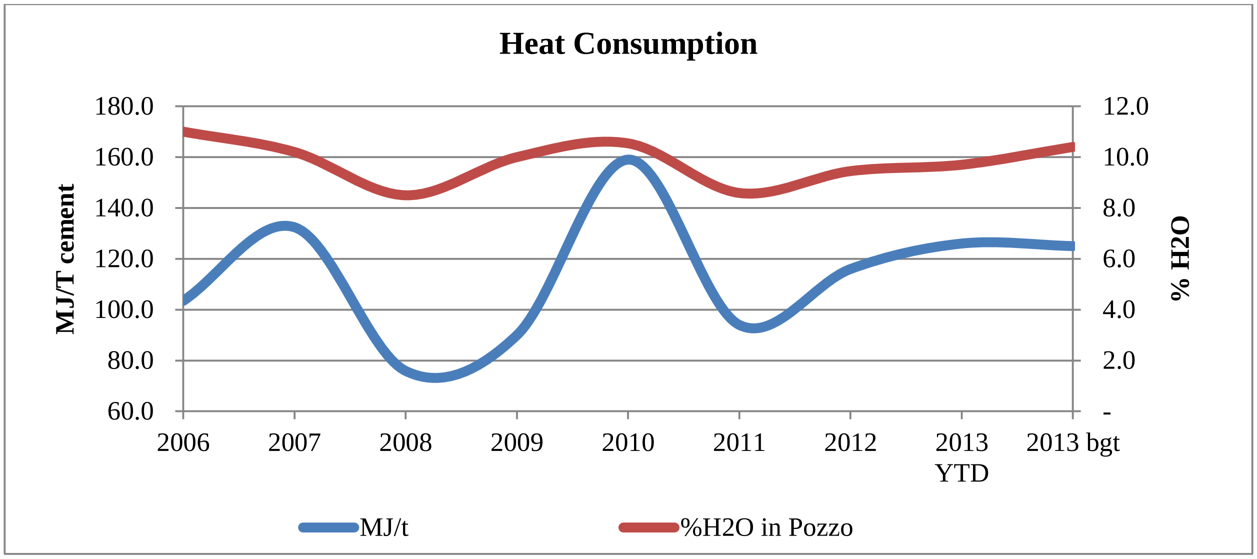

Figure 1.1: The Relationship Between % of Water in Pozzolana and Amount Energy Consumed in MJ Per Ton of Cement

Source :(NGP Annual report, 2013)

From figure 1.1 heat consumption is affected by the amount of moisture to be removed from the pozzolana. High amount of water in pozzolana leads to high heat consumption.

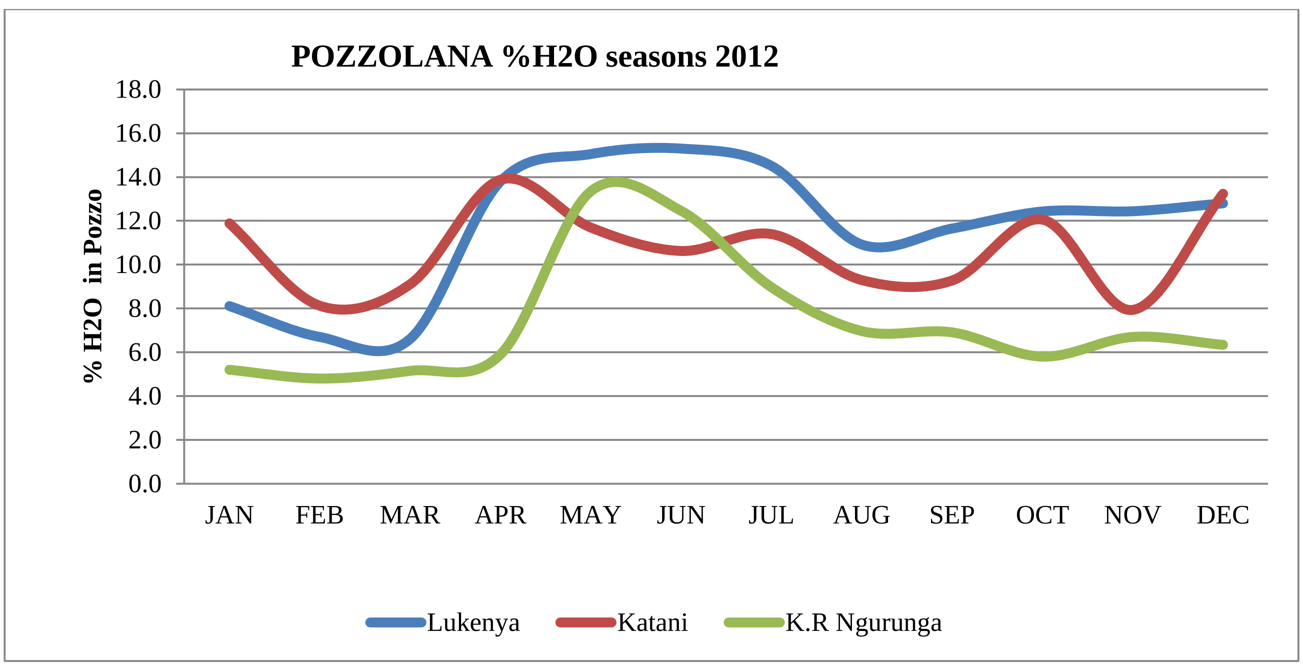

Figure 1.2: Percentage of Water in Pozzolana from Various Sources for Various Seasons.

Source :(NGP Annual report, 2013)

From figure 1.2 Pozzolana from Lukenya has high moisture content while pozzolana from K.R Ngurunga has low moisture content. Moisture content in pozzolana is high between April and July rainy season.

The world economic growth in the past century has depended largely on the ever expanding use of hydrocarbon as an energy source. Due to the fact that there has been overdependence on these energy sources which are non-renewable their prices are rising and in the near future we shall be experiencing an energy crunch. Figure 1.3 indicates the fuel cost trend of HFO used in Bamburi Nairobi grinding plant over years.

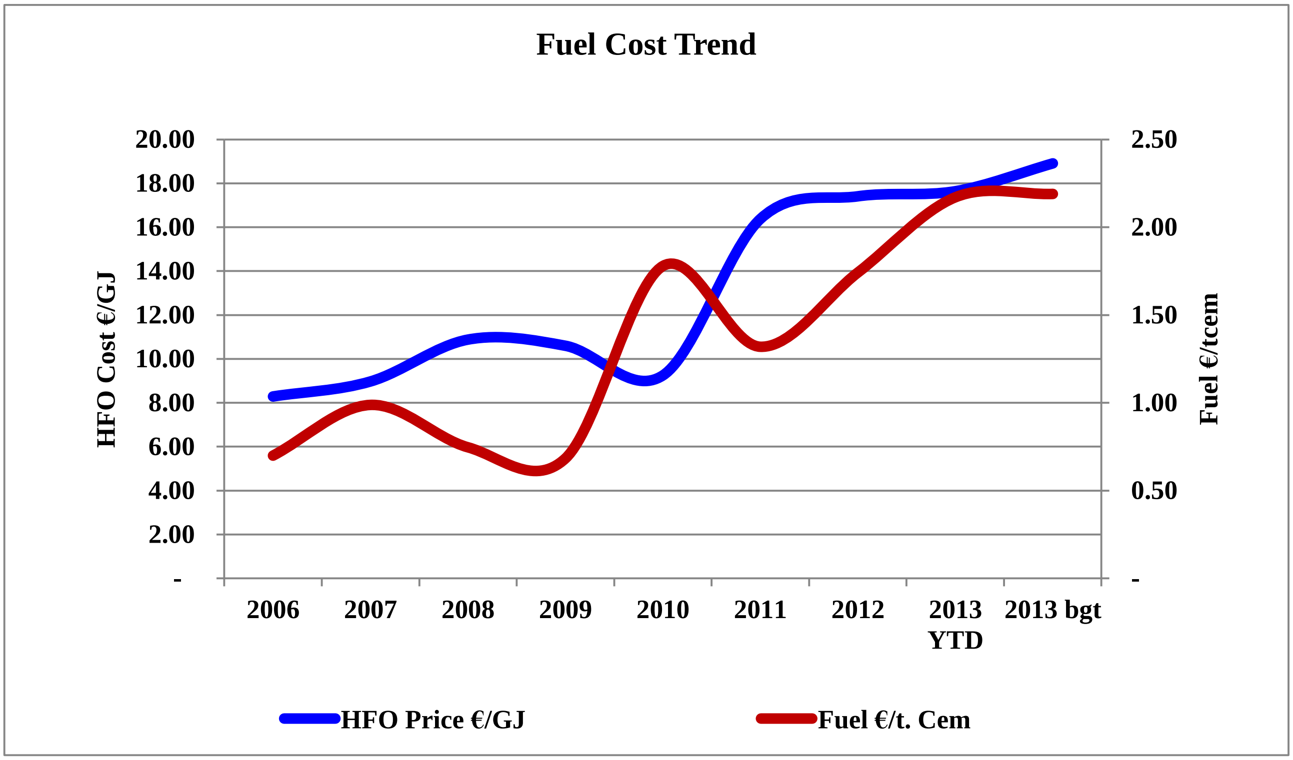

Figure 1.3: Fuel Cost Trend

Source :(NGP Annual report, 2013)

From figure 1.3 the cost of HFO per GJ requirement has been fluctuating over the years and has been increasing significantly from 2010. This has led to fluctuating cost of fuel per tonne of cement produced.

1.1.1 The Drying Process

Figure 1.4 shows the cement drying process. The existing pozzolana dryer installation basically consists of HGG fired with HFO and waste oil drum dryer, filter and exhaust fan.HFO is transferred to the air-fuel mixing chamber of the burner. LPG is also introduced in the mixing chamber to improve the ignition of the fuel. Atomizing compressed air at 31°C is introduced to the atomizing unit where it meets primary and secondary air. Atomized air and fuel then mix and ignition and combustion take place while flue gasses are generated. The dryer slopes slightly so that the discharge end is lower than the material feed end in order to convey the material through the dryer under gravity. Material to be dried enters the dryer, and as the dryer rotates, the material is lifted up by a series of internal fins lining the inner wall of the dryer. When the material gets high enough to roll back off the fins, it falls back down to the bottom of the dryer, passing through the hot gas stream as it falls. This gas stream is moving towards the discharge end from the feed end (known as co-current flow) by help of a suction fan. The gas stream is made up of a mixture of air and combustion gases from a burner, in which case the dryer is called a direct heated dryer. Wet gypsum and pozzolana are dried then conveyed through conveyor and elevator system to their storage silos.

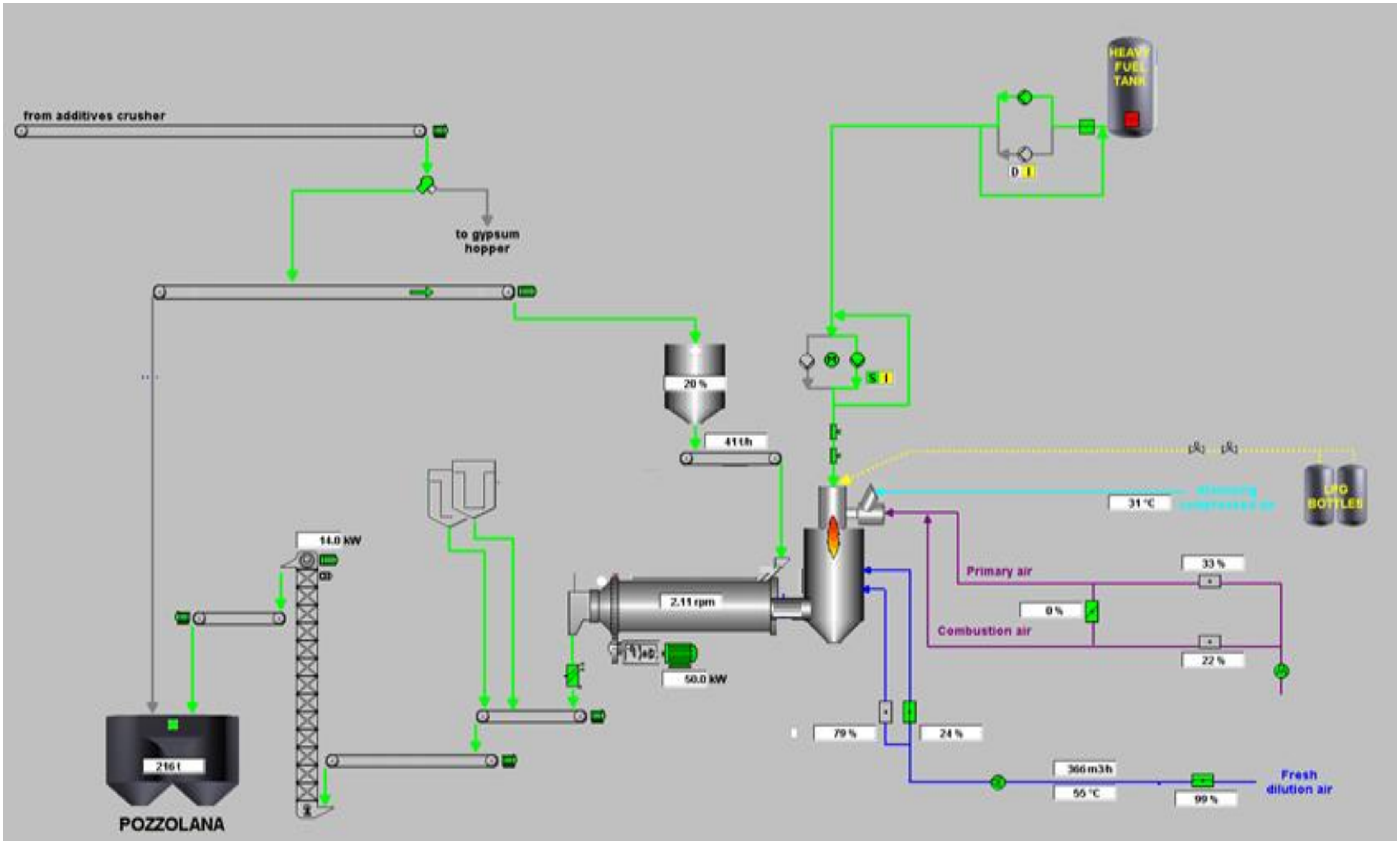

Figure 1.4: Cement Drying Process

Source: (Cement Production Process NGP, 2013)

1.1.2 Cement Grinding Process Description

Figure 1.5 shows the cement grinding process. The materials to be ground which include 62% clinker, 21% pozzolana and 17% gypsum are fed to a belt conveyor to a funnel receiver of the cement mill at a rate of 83 ton/hr. A 2750 kW motor is used to drive the cement mill which grinds these materials at a rate of 224 ton/hr. The finely ground mixture is then conveyed via belt conveyor which then transfers it to an elevator which then transfers the material to another belt conveyor then the material is conveyed to a cyclone for separation. Ungrounded material is transferred through conveyor system to the funnel receiver of the grinding mill at a rate of 141 ton/hr for further grinding. The further ground material is transferred through a belt conveyor to an elevator then through another belt conveyor to the storage silos.

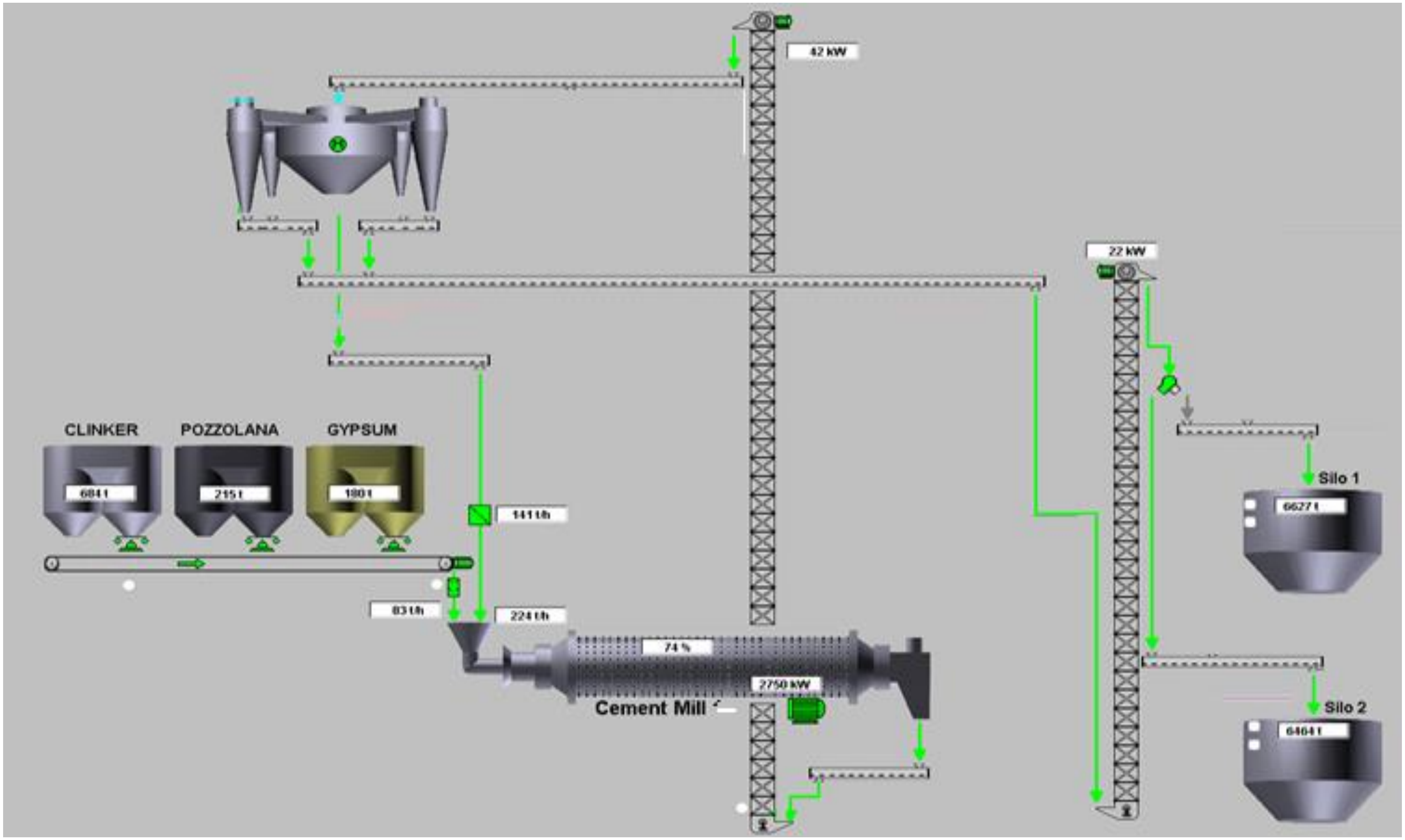

Figure 1.5: Cement Grinding Process

Source: (Cement Production Process NGP, 2013)

1.2 Problem Statement

There has been overreliance on fossil fuels in many manufacturing industries over the years.This has led to evident increase of cost of fuel and increasing production cost. The cost increase is caused by hidden costs which are not paid for by the companies that produce and sell energy but are passed on to the consumers of the energy. These costs include climate change adaptation costs, climate change damage costs, and fossil fuel dependence costs. These costs are indirect and difficult to determine, therefore they have traditionally remained external to the energy pricing system, and are thus often referred to as externalities. Hence the overreliance on fossil fuels results in damage to human health, the environment, and the economy. (www.ucsusa.org, 19.09.2013). Again the fossil fuels being relied on for industrial energy supply will most probably be depleted within a few hundred years.

The increased threat to the availability of fossil fuel energy has give rise to a growing concern on the need to substitute it with alternative sources of energy in both transport and industrial sectors. Previous studies carried out to address this concern have aimed at reducing CO^2 emission by substitution and focused on price elasticity of the inter fuel substitution using mathematical models. The previous studies have used data obtained from entire production process involved in cement manufacturing industries. This however faces the challenge of generalization given that the different operational areas of the manufacturing system for cement are likely to have different energy consumption patterns and requirements. There is however a need to apply the lessons learned from the studies using the mathematical models to study the inter-fuel substitution in specific operational areas of the cement manufacturing sectors that consume large quantities of fossil fuels and observe the behavior of the different processes. Such an observation can be done when an experiment is designed to assess the variation in energy cost behavior at different levels when the fossil fuels are substituted with alternative fuels. At the cement grinding stage of the process, it is possible to carry out this substitution since pozzolana drying falls in this category of sectors that consumes large quantities of fossil fuels. The stage is also recognized as an important source of CO_2 emissions.

Substantial potential for energy efficiency improvement exists in the pozzolana drying a portion of this potential can be achieved as part of modernization and expansion of existing facilities. At

Bamburi cement Limited an opportunity exists where pozzolana dryer can be modified to accommodate biomass for substitution. This is because biomass is the most cost-effective and practical and therefore offers the most realistic and sustainable energy strategy. Therefore, this study analyses the energy cost savings by substituting HFO with biomass for a pozzolana dryer in order to achieve sustainable energy strategy by improving the existing dryer to accommodate the use of alternative fuels.

1.3 Objectives of the Study

1.3.1 General Objective

To analyze of energy cost implications of substituting HFO with biomass for a pozzolana Dryer

1.3.2 Specific Objectives

i. To study the existing system and establish the energy situation of the existing dryer and the auxiliary system to handle biomass.
ii. To compare projected substitution scenarios with actual substitution
iii. To carry out the economic analysis of the project in order to determine the viability of fuel substitution

CHAPTER TWO: LITERATUREREVIEW

2.1 Overview of the Cement Manufacturing Process

Cement is an important construction ingredient around the world, and as a result, cement production is a significant source of global carbon dioxide (CO_2) emissions, making up approximately 2.4 percent of global CO_2 emissions from industrial and energy sources Marland et al. (1989). Cement is produced in large, capital-intensive production plants generally located near limestone quarries or other raw carbonate mineral sources as these sources are the principal raw materials used in the cement production process. Because the production plants are expensive, the number of plants in a country is generally limited (less than 100). Carbon dioxide is emitted as a by-product of clinker production, an intermediate product in cement manufacture, in which calcium carbonate ($CaCO_3$) is calcinated and converted to lime (CaO), the primary component of cement. CO_2 is also emitted during cement production by fossil fuel combustion. However, the CO_2 from fossil fuels are specifically accounted for in emission estimates for fossil fuels.

According to Madlool et.al (2011) a sizeable amount of energy is used in manufacturing cement. Therefore focus should be given on the reduction of energy and energy related environmental emissions locally and globally. Being an energy intensive industry, typically it accounts for 50–60% of the total production costs. Thermal energy accounts for about 20–25% of the cement production cost. The typical electrical energy consumption of a modern cement plant is about 110–120 kWh per ton of cement. The main thermal energy is used during the burning process, while electrical energy is used for cement grinding. World demand for cement was 2283 million tonnes in 2005 and China accounted for about 47% of the total demand. Figure 2.1 shows the world cement production 2012 by region and main countries involved in cement production

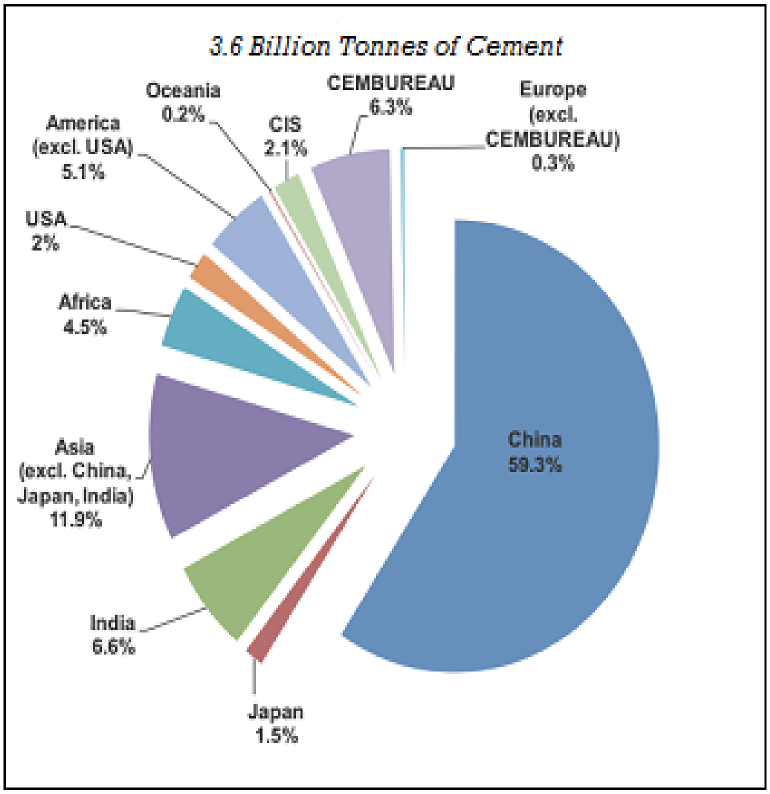

Figure 2.1: World Cement Production 2012, by Region and Main Countries

Source: (IMF World Economic Outlook, 2013)

Fossil fuels, such as coal and petroleum coke, have traditionally been used as energy sources in the cement manufacturing industry. However, in recent decades, these fuels are increasingly being substituted with alternative fuels typically residue-based sources (e.g., sorted municipal solid waste, tires, and waste wood.) (Albino et al, 2011)

A cement production plant consists of the following three processes which include: extraction of raw materials; raw grinding and burning and finish grinding process. The raw materials needed to produce cement (calcium carbonate, silica, alumina and iron ore) are generally extracted from limestone rock, chalk, clayey schist or clay. Suitable reserves can be found in most countries. These raw materials are extracted from the quarry by blasting. They are then crushed and transported to the plant where they are stored and homogenized. For raw grinding and burning, Very fine grinding produces a fine powder, known as raw meal, which is preheated and then sent to the kiln. The material is heated to 1,500°C before being suddenly and dramatically cooled by bursts of air. This produces clinker, the basic material required for the production of all cements.

The last step is Cement grinding and shipping, where a small amount of gypsum (3-5%) is added to the clinker to regulate how the cement will set. The mixture is then very finely ground to obtain "pure cement". During this phase, different mineral materials, called "cement additives", may be added alongside the gypsum. Used in varying proportions, these additives, which are of natural or industrial origin, give the cement specific properties such as reduced permeability, greater resistance to sulfates and aggressive environments, improved workability, or higher-quality finishes. Finally, the cement is stored in silos before being shipped in bulk or in bags to the sites where it will be used (http://www.lafarge.co.ke).

2.2 Fuel Energy Costs

During the past century, world economic growth has depended largely on ever-expanding use of hydrocarbon energy sources: oil for transportation, coal and natural gas for electricity generation, oil and gas for agricultural production. It is no exaggeration to say that the health of the global economy currently hinges on increasing rates of production of these fuels. However, oil, gas, and coal are non-renewable resources that are typically extracted using the “low-hanging fruit” principle. That is, large concentrations of high-quality and easily accessed fuels tend to be depleted first. Thus, while the world is in no danger of running out of hydrocarbon energy sources anytime soon, oil, gas, and coal extraction efforts are increasingly directed toward low-quality, hard-to-produce fuels that require higher up-front investment and entail increasing environmental costs and risks. The dependence of the world economy on oil is illustrated by the close correlation between oil price spikes and US economic recessions that has been noted by several analysts. The cost of developing a new barrel of oil’s worth of production capacity has increased dramatically in recent years. In 2000, the oil industry remained profitable with prices pivoting around $20 per barrel. Today it is estimated that oil prices of $60 to $80 per barrel are required in order to incentivize new exploration and production in many prospective regions. (www.oilprice.com).

A wide variety of fuels are available for thermal energy supply some of them include: fuel oil, LPG, coal lignite and wood. Understanding fuel cost is fairly simple as it is purchased in tons or litres. Availability cost and quality are the main factors that should be considered while purchasing. The factors that are usually taken into account during procurement of fuels for energy efficiency and economics are: price at source, transport charge and type of transport: quality of fuel and energy content (calorific value). Fuel substitution includes substituting existing fossil fuels with more efficient and less cost/less polluting fuels such as natural gas, biogas and other locally available agro residues.

NGP uses heavy fuel oil for its drying process. The fuel is supplied by oil tankers and offloaded to site tanks for consumption. The oil in the tanks is pumped through lagged and partly heated pipes to the burner. The plant uses swirl and rotary cap atomizing technologies in the existing burners. The HFO used is metered and the readings are the basis of evaluating oil use. The average monthly consumption is about 150,000 litres. The current burner has a provision for use of alternative fuels such as coffee husks or rice husks which brings about this research study.

2.3 Biomass as an Alternative Fuel

Biomass is the oldest source of energy, in use since mankind first harnessed fire and used wood as a source of heat, light, and power. For centuries before the invention of the steam and internal combustion engines, most of the world's energy came from biomass. The advent of industrialization created the need for a large quantity, and more concentrated source, of energy. This led to large-scale exploration and utilization of fossil fuels (Winandy *et al*, 2008). Nonetheless, biomass still accounts for 10 percent of global energy use, which is approximately five times more than the energy generated from hydroelectric power (IEA, 2006). In the United States alone, about 11 Giga watts (GW) of electrical power are generated from bio-energy sources. This makes biomass the second-largest US renewable energy source next to hydropower (94 GW), and more significant than wind energy (5 GW) and geothermal (2.7 GW) (Nicholls *et al*, 2008).

With the growing realization of the impact of fossil fuels on global warming, coupled with volatile energy prices and an emerging energy security agenda, there is a renewed interest in using biomass as a carbon-neutral and cost-effective alternative. For example, Nicholls *et al* (2008) state that wood energy could potentially supply up to 10 percent of U.S energy demand. Currently it is below four percent and is expected to grow to five percent by 2020.

According to Warnken Ise, (2003) alternative fuels that are being used by cement kilns to replace traditional fossil fuels include tyres, carbon anode dust & spent pot linings from the aluminium industry, a blend of recovered oils, dewatered sludge and grease trap emulsions and solvent based fuel. These alternative fuels currently account for approximately 6 per cent of thermal energy requirements for the Australian Cement Industry. There are also a range of biomass-based alternative fuels that can to be used by cement kilns including wood, tallow, dried bio-solids, wheat residues, rice hulls, the woody component from composted organics, grape marc (residual skins from winemaking) and some types of process engineered fuel (for example, residual paper from material recovery facilities - MRFs). The uptake of biomass-based alternative fuels is in its infancy, but is poised to increase in the coming years to similar tonnages as for existing alternative fuels. This would put biomass fuel use at 45,000 tonnes per annum (tpa) out of a total alternative fuel use of approximately 100,000 tpa. (However, biomass-based alternative fuels generally provide less thermal energy per tonne when combusted than the average existing alternative fuels, meaning that the 'energy delivered' difference will be greater than the 'tonnes delivered'.) Advantages of using biomass as a replacement fuel include conservation of non-renewable fossil fuels, reduction in greenhouse gas emissions by offsetting fossil fuel use, recovery of a higher resource value from previously wasted materials, conservation of landfill space in some instances, a reduction in Nitrogen Oxide (NOx), ability to utilize complementary alternative materials owing to reduction in ash content (coal replacement), less concerns regarding the composition of the fuel from a technical and community perspective (as compared against other alternative fuels) and an overall improved environmental performance. Additional benefits of a financial nature in terms of lower cost of fuel are also realized. Barriers to the use of biomass include the capital cost for new processing and handling equipment (both on and off site), transport and logistics arising from the dispersed nature of the sources of the biomass fuel, process issues such as managing the quality of the fuel, wear on refractory brick linings, kiln ring build-up, lower productions rates and changed material recipe. As the use of biomass-based alternative fuels is just beginning, there are still challenges to overcome in order to harness all of the advantages that biomass fuels have to offer the cement industry. These include gaining a 'community license to operate', gaining regulatory approval and gaining access to potential supply that achieves the right balance of economic benefits for the fuel supplier and user.

With the growing realization of the impact of fossil fuels on global warming, there is a renewed interest in the utilization of biomass as a renewable and carbon-neutral energy source. The use of biomass and waste fuels is a growing area based on sound economic and environmental benefits.

Biomass fuel-switching is possible, achievable and beneficial to the environment and companies that are willing to embrace it. Once implemented, companies can also benefit from the generation of carbon credits through the Clean Development Mechanism (United Nations Development Programme, 2009).

According to UNDP (2009), some alternative biomass fuels have lower energy-specific CO_2 emissions than coal; others have higher emissions. Hence, absolute carbon content does not provide the rationale for switching from coal to biomass. Rather, the critical aspect of biomass in this regard is that it can, in certain circumstances, be regarded as a net zero emission fuel-source, even if CO_2 is liberated during its combustion. If biomass, or biomass residues, is/are cultivated sustainably that is, if the rate of biomass extraction is not higher than the rate of biomass replanting or replenishment then the biomass is considered to be 'carbon-neutral'. The logic is that the biomass grown to replace the combusted biomass is considered to absorb CO_2 from the atmosphere while growing, thereby in effect 'cancelling out' the CO_2 emissions associated with the combustion of the cultivated biomass: the net effect on the atmospheric carbon balance is zero. Sustainably-cultivated biomass has, in effect, an emission factor of zero. It is evident, then, that fuel switching, particularly to carbon-neutral biomass, can significantly reduce net CO_2 emissions.

2.4 Fuel Substitution

According to a study carried out by U.S energy information administration (2012) the elasticities of substitution in the power sector indicate that industry does have some flexibility to alter the generation fuel mix in response to changing prices. However, overall, the estimated substitution elasticities are relatively low, with the exception of fuel displacement between petroleum and natural gas. There are many other factors besides price that can affect the fuels used for power generation, such as available capacity, local transmission and reliability constraints, fuel purchase or power supply contracts, and environmental regulations.

Econometric models of inter-fuel substitution are applied to aggregate energy use, as well as to a specific energy use process thermal heating where inter-fuel substitution is technologically feasible. Compared to the aggregate data, the estimated own-price elasticities for all fuels and the cross-price elasticities for fossil fuels are considerably higher for thermal heating processes. Nonetheless, electricity is found to be a poor substitute for other fuels based on both aggregate data and, separately, for the heating process. An increase in real fuel prices from the Climate Change Levy in 2001 resulted in higher substitution elasticities based on aggregate data, and lower substitution elasticities for the thermal heating process. The results of a counterfactual decomposition of change in the estimated elasticities indicate that technological change was the major determinant of the differences in observed elasticities before and after the energy price increase (Steinbuks J, 2012).

2.5 Industrial Process Emissions

The cement manufacturing industry is also under increasing pressure to reduce emissions. Cement manufacturing releases a lot of emissions such as carbon dioxide (CO_2) and nitrogen oxide (NOx). It is estimated that 5 percent of global carbon dioxide emissions originate from cement production (Hendriks, et al, 1998). The use of alternative fuels in cement manufacturing, therefore do not only afford considerable energy cost reduction, but they also have significant ecological benefits of conserving non-renewable resources, the reduction of waste disposal requirements and reduction of emissions. Use of low-grade alternative fuels in some kiln systems reduces NOx emissions due to re-burn reactions. There is an increased net global reduction in CO_2 emissions when waste is combusted in the cement kiln systems as opposed to dedicated incinerators.

According IPCC (2007), energy supply i.e. burning of coal natural gas and oil for electricity and heat contribute to 26% of global gas emission. Global GHG emissions from industry contribute to 19% of total gas emission. These primarily involve fossil fuel burnt on site as facilities for energy. This sector also includes emissions from chemical, metallurgical and mineral transformation process not associated with energy consumption. Carbon dioxide from fossil use contributes to 57% of global GHG emission.Global carbon emissions from fossil fuels have significantly increased since 1900. Emissions increased by over 16 times between 1900 and 2008 and by about 1.5 times between 1990 and 2008. Figure 2.2 shows the trend.

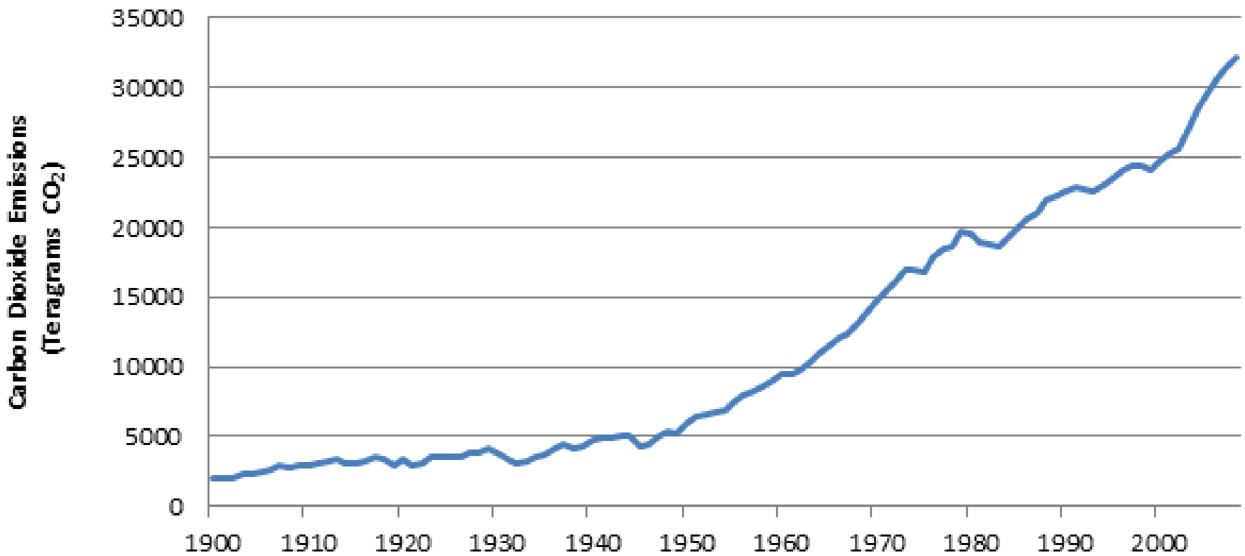

Figure 2.2: Global Carbon Dioxide (CO_2) Emissions from Fossil-Fuels 1900-2008

Source: Boden et al (2010)

According to Energy Information Agency, (2002) industrial emissions of carbon dioxide not caused by the combustion of fossil fuels accounted for only 1.2 percent (18.8 million metric tons carbon equivalent) of total U.S. carbon dioxide emissions in 2001 Process-related emissions from industrial sources depend largely on the level of activity in the construction industries and on production at oil and gas wells. These sources include limestone and dolomite calcination, soda ash manufacture and consumption, carbon dioxide manufacture, cement manufacture, and aluminum production. Sixty percent of the carbon dioxide emissions from industrial processes are from cement manufacture. When calcium carbonate is heated (calcined) in a kiln, it is converted to lime and carbon dioxide

The cement industry contributes about 5% to global anthropogenic CO_2 emissions, making the cement industry an important sector for CO_2-emission mitigation strategies. CO_2 is emitted from the calcination process of limestone, from combustion of fuels in the kiln, as well as from power generation. Estimated total carbon emissions from cement production in 1994 were 307 million metric tons of carbon (MtC), 160 MtC from process carbon emissions, and 147 MtC from energy use. Overall, the top 10 cement-producing countries in 1994 accounted for 63% of global carbon emissions from cement production. The average intensity of carbon dioxide emissions from total global cement production is 222 kg of C/t of cement. Emission mitigation options include energy efficiency improvement, new processes, a shift to low carbon fuels, application of waste fuels, increased use of additives in cement making, and, eventually, alternative cements and CO2 removal from flue gases in clinker kilns (Worrell. E et al, 2001).

CHAPTER THREE: METHOD AND MATERIALS

3.1 Methodology

A pilot auxiliary system to handle biomass for substitution system was designed and fabricated where the study was carried out in order to evaluate the feasibility of the substitution project. Data was collected for a period of 20 days where GJ of HFO and AF used for a number of hours of running the dryer for different percentages of substitution were obtained. This data was analyzed to get the total cost of HFO, AF and energy per year which was presented inform of graphs. Again a projected substitution scenario was carried out for the purposes of comparison and drawing of conclusion on the viability of this project. Various tests were also carried out on the auxiliary system for the purposes of analysis which included;

3.1.1 Determining the Energy Situation of the Existing Dryer

Before the implementation of the auxiliary system energy requirements and the expenditure on fuel of the existing dryer were determined. This information was from previous reports from previous years. The report included energy requirements, HFO usage and cost of HFO in that year. This report was a benchmark of comparing the changes that may have occurred after the implementation of the auxiliary system.

3.1.2 Study of an Auxiliary System to Handle Biomass

An auxiliary system which consisted of the holding unit, the rotary feeder system, blower and the piping system was designed. The holding unit capacity blower and the piping system capacity and entry requirements were analyzed.

3.1.3. Comparison of projected substitution scenario with actual substitution

Both projected and actual substitution scenarios were carried out. The projected substation scenario was the benchmark of evaluation of the expectations of the actual substitution. Again fuel composition and cost which included the alternative fuel and HFO of both scenarios were compared .The comparison was necessary to draw a conclusion of the efficiency of the actual substation system

3.1.4 Economic Analysis

This section looked at various aspects of economics of fuel substitution which included; capital expenditure, operational expenditure, cost benefit analysis and energy expenditure equilibrium of substitution and technical analysis of the project. These were based on the pilot project and compared with the projected substitution scenarios.

a. Capital expenditure

Capital expenditure for the fuel substitution system was calculated based on the pilot was the design and the installation of the auxiliary system. This included: electrical connection & controls; fuel feeding system; fuel store; design, steel structures material cost, mechanical installation, and labour.

b. Operational expenditure

Operational expenditure considered here included both the ongoing costs of fuel and attendance and the maintenance costs in the pilot auxiliary system installed. The following were considered for the operational expenditure: biomass fuel and delivery costs; residual fossil fuel costs; attendance costs and maintenance costs. Where a biomass system is considered primarily on financial grounds payback term and Return on Investment (ROI) were calculated to determine if the project was acceptable.

$$\text{Simple payback period} = \frac{\text{capital invested}}{\text{annual savings}} \tag{1}$$

$$\text{ROI} = \frac{\text{Gain from investment} - \text{cost of investment}}{\text{cost of investment}} \tag{2}$$

c. Cost Benefit Analysis

Cost benefit analysis was done to give management a picture of the costs, benefits and risks. Cost benefit was to determine the benefits and savings that were expected from the system and compare them with the expected costs. The cost benefit analysis was carried out based on the pilot project and a projection was also done to give clear implications of the costs and benefits to be incurred if an actual system was to be installed.

Table 3.1: Cost for the Pilot Project

Year / Category	1	2	3	4	5
Plant cost					
Installation cost					
Maintenance cost					
Fuel handling cost					
Cost at the end of the year					
Cumulative cost					

Table 3.2 Benefits of the Pilot Project

Year / Category	1	2	3	4	5
Fuel cost Reduction					
Benefits at the end of the year					
Cumulative Benefits					

d. Equilibrium of Substitution

This was measure of the responsiveness of producers in swapping inputs when the relative prices of those inputs change. Producers tend to favour the input that has the lowest overall cost. In this research we were determining the best percentage of substitution for best utilization of fuel.

e. Technical Analysis of the Project

The aim of this analysis was to decide whether the project is soundly designed, appropriately engineered and followed accepted standards. It primarily concerned sources and availability of biomass, its effects on the quality of processed cement and the need of auxiliary equipment to modify the existing design of the equipment to handle the substitute fuel. It also included other such factors as availability of required professional, technicians and workers.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Introduction

This chapter represents the results of the of the research study. Data was analyzed and discussed. This was done in order to establish if the substitution of AF fuels was necessary, to what degree should it be done and what modification are necessary to be done to the existing system.

4.2 Fuel Composition and Consumption of the Existing Dryer

The existing dryer was running on HFO only. HFO was introduced to the air fuel mixing chamber of the burner at a mass flow rate of 2617 kg/hr. There it was mixed with atomized combustion air at 31◦C. The mixture was then transferred to the hot gas generator where it is diluted with dilution air at 25◦C and ignition then takes place. Hot gasses were generated at a temperature of 930◦C. The contents of the hot gases were O_2, NO_x, SO_2 and dust. The hot gases were then directed to the dryer where pozzolana to be dried was introduced at a mass flow rate of 140,000kg/hr and 22% moisture content. The dryer was set at a speed of 2 rpm. The dried pozzolana was then transferred to a discharge hopper where it was discharged at 9,042,857 kg/hr and a maximum moisture content of 2% and temperature of 80◦C. Dryer outlet gasses were let out at a temperature of 110◦C. The heat and mass balance of the dryer is represented in figure 4.1.

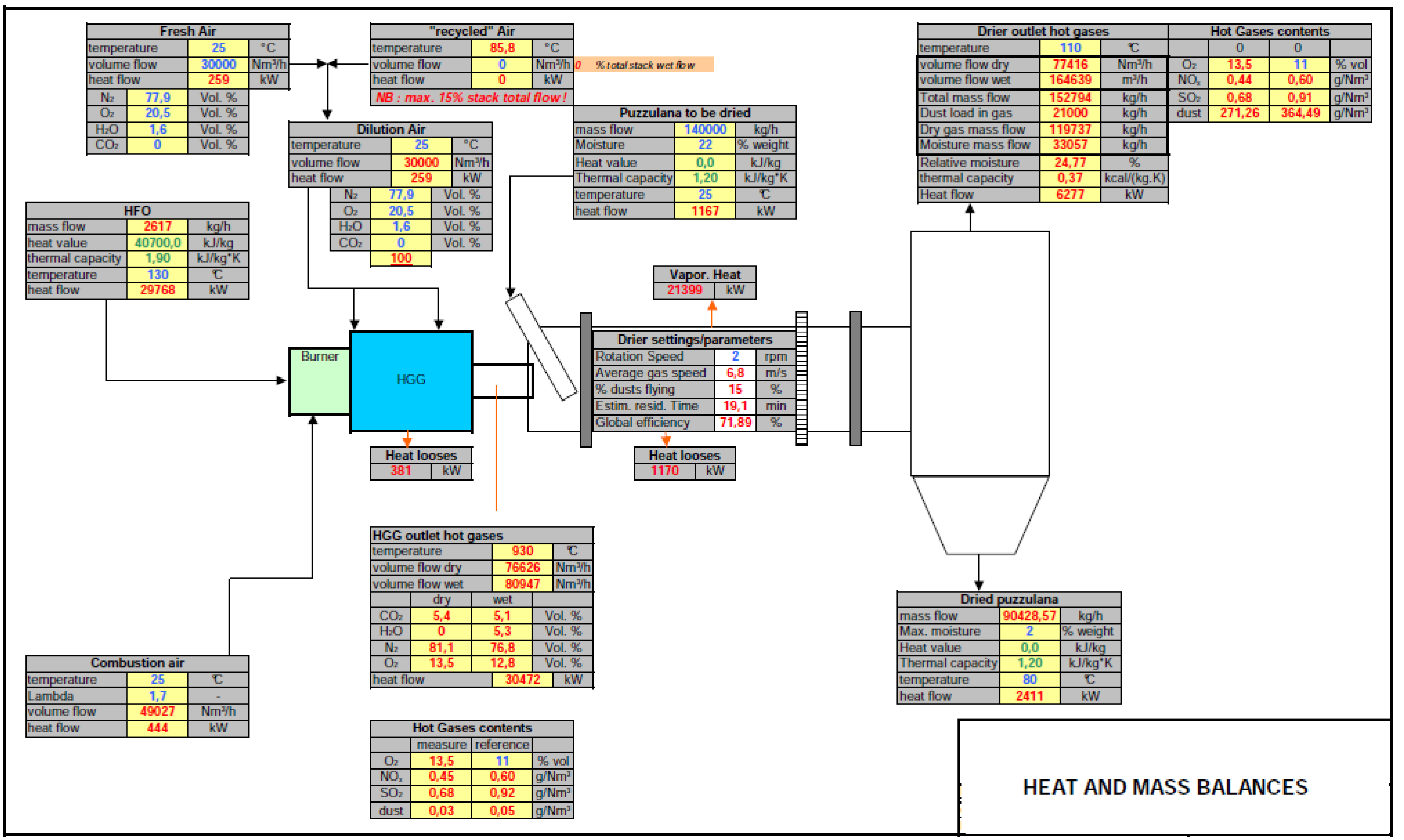

Figure 4.1: Heat and Mass Balance

Source: (Cement Production Process NGP, 2013)

4.3. Pilot Auxiliary System.

An auxiliary system was designed and fabricated to handle and deliver the AF fuel. It consisted of a blower run by a 30kW motor, venturi, rotary feeder run by a 20kW motor, a hopper of 2 tonne capacity and piping system of diameter of 150mm to the burner. The blower through centrifugal force propels air forward giving it some velocity. When the air reached the venturi there was a pressure drop and increase of velocity of the air. At the same time rice husks flow down the hopper and discharged through the rotary feeder. They are then blown though the piping system into the burner where they are mixed with HFO. The rice husks were introduced at various percentages of substitution and data recorded as shown in table 4.2. The line presentation of the auxiliary system is as shown in figure 4.2.

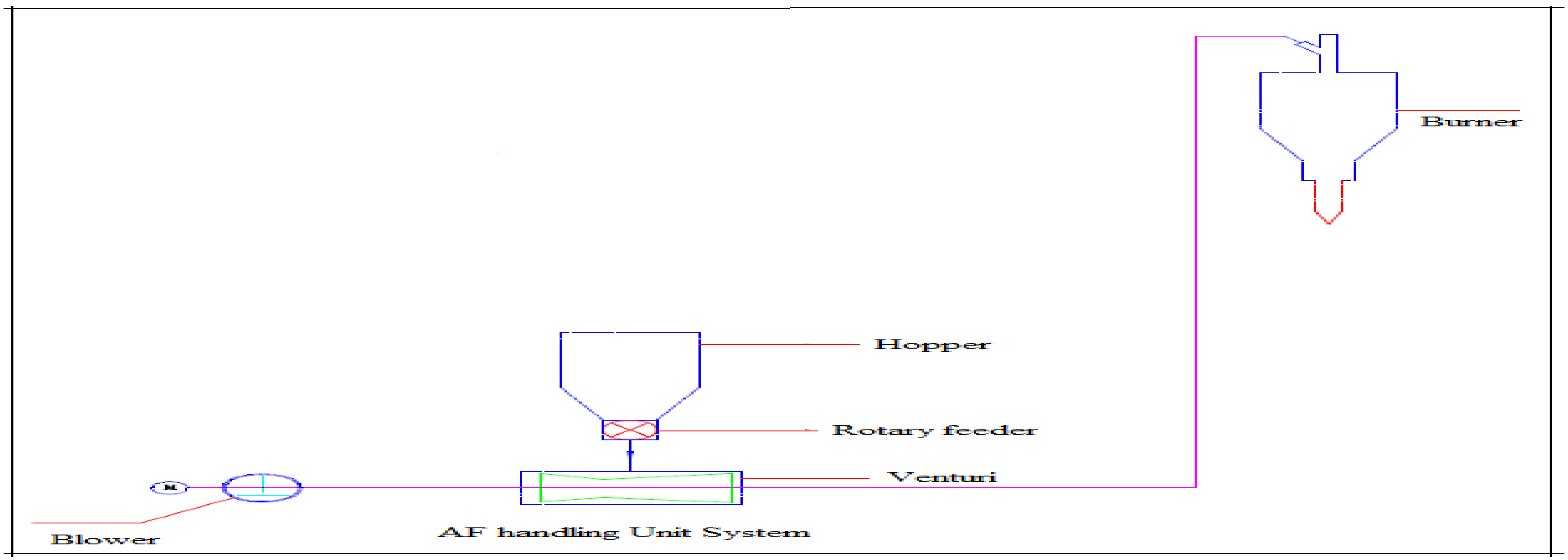

Figure 4.2: Auxiliary System

Source: (Cement Production Process NGP, 2013)

4.4 Comparison of Projected Substitution Scenario with Actual Substitution

4.4.1 Projected Substitution Scenario

A projected substitution scenario was carried out to foresee the nature of results to be expected in real substitution. The procedure below was carried out for the year 2014.

Given;

i. HFO price Kes/kl= 76599.79 = A
HFO density ton/kl =0.92 = B
HFO LHV GJ/ton = 39.77 = C

Source :(NGP annual Report, 2012)

Therefore;

HFO Kes/GJ = $\frac{A \div B}{C} = D$

$$\frac{76{,}599.79 \div 0.92}{39.79} = 2{,}093.47$$

ii. Assuming 1 € =116 Kes

Therefore HFO €/GJ =$\frac{D}{116} = \frac{2093.47}{116} = 18.05$= E

iii. Budget MJ/t Cement =125 =F
Budget ton of cement in 2014 =1366120.6 =G

Source :(NGP annual Report, 2012)

Budget GJ/Yr =$\frac{F \times G}{1000} = \frac{125 \times 1366120.0}{1000} = 170765.08$ = I

iv. Assuming there was additional cost of labour to handle alternative fuel at 12%
Alternative fuel LHV GJ/t = 12.70

Source :(NGP annual Report, 2012)

Alternative fuel €/GJ = (1+12%) x (4.39+0.4) = 5.36

Where 4.39= cost of rice husks per Giga joule
0.4 = cost of bags per giga joule

Source :(NGP annual Report, 2012)

Alternative fuel kes/GJ =5.36 x 116 = 622.32

Where

1 € = 116 kes.

v. Therefore

HFO Cost $= \boldsymbol{I} \times (\mathbf{1} - \%\boldsymbol{AF}) \times \boldsymbol{E}$

Where;

I = budget GJ/yr

E= HFO kes/GJ

AF fuel cost = (Budget GJ/yr x AF substitution %) x AF cost in Kes/ GJ

The projected substitution scenarios were calculated using excel program and tabulated in the table 4.1 below.

Table 4.1 Projected Substitution Scenarios

DESCRIPTION	0%	5%	10%	15%	20%	25%
HFO Cost (Kes)	357,491,491.33	339,616,916.77	321,742,342.20	303,867,767.63	285,993,193.07	268,118,618.50
AF Cost (Kes)	-	5,313,498.75	10,626,997.50	15,940,496.25	21,253,995.01	26,567,493.76
Total Cost (Kes)	357,491,491.33	344,930,415.52	332,369,339.70	319,808,263.89	307,247,188.07	294,686,112.26
Savings (Kes)	-	12,561,075.82	25,122,151.63	37,683,227.45	50,244,303.26	62,805,379.08

DESCRIPTION	30%	35%	40%	45%	50%
HFO Cost (Kes)	250,244,043.93	232,369,469.37	214,494,894.80	196,620,320.23	178,745,745.67
AF Cost (Kes)	31,880,992.51	37,194,491.26	42,507,990.01	47,821,488.76	53,134,987.51
Total Cost (Kes)	282,125,036.44	269,563,960.63	257,002,884.81	244,441,809.00	231,880,733.18
Savings (Kes)	75,366,454.89	87,927,530.71	100,488,606.52	113,049,682.34	125,610,758.15

4.4.2: Actual Substitution Scenarios

An actual test of the substitution was carried out at various percentages for twenty days to establish GJ of HFO and AF used. The data was further analysed to establish the amount of energy used per day per hour and per year and tabulated in table 4.2.

Table 4.2: Actual Substitution Data

Day	1	2	3	4	5	6	7	8	9	10
%substitution	0.00	1.26	3.74	4.15	5.18	5.95	6.76	7.70	8.02	9.55
GJ of HFO Used	425.87	515.80	628.28	468.05	286.26	648.70	573.73	587.74	504.75	543.27
GJ of AF used	0.00	7.01	18.80	19.30	22.91	41.02	47.54	57.49	54.31	64.25
Total GJ	425.87	522.81	647.08	487.35	309.17	689.72	621.27	645.23	559.06	607.52
Hours of running dryer	11.85	14.78	19.12	15.98	10.22	22.92	20.52	21.72	18.75	21.00
GJ/hr of HFO	35.94	34.90	32.86	29.29	28.01	28.30	27.96	27.06	26.92	25.87
GJ/hr of AF	0.00	0.47	0.98	1.21	2.24	1.79	2.32	2.65	2.90	3.06
Total GJ/hr	35.94	35.37	33.84	30.50	30.25	30.09	30.28	29.71	29.82	28.93
GJ/day of HFO	862.52	837.56	788.64	702.95	672.23	679.27	671.03	649.44	646.08	620.88
GJ/day of AF	0.00	11.38	23.60	28.99	53.80	42.95	55.60	63.52	69.52	73.43
Total GJ/day	862.52	848.95	812.23	731.94	726.04	722.22	726.63	712.96	715.60	694.31
GJ/year of HFO	314820.35	305710.96	287852.13	256578.10	245365.71	247932.46	244925.67	237044.31	235819.20	226621.20
GJ/year of AF	0.00	4154.78	8613.39	10579.97	19637.14	15677.80	20294.85	23186.57	25373.63	26801.43
Total GJ/Yr	314820.35	309865.74	296465.52	267158.07	265002.86	263610.26	265220.53	260230.88	261192.83	253422.63
Cost of HFO/Year	658919001.82	639853040.87	602474516.23	537017958.32	513550440.00	518922640.31	512629432.57	496133739.56	493569585.60	474318171.60
Cost of AF/Year	0.00	2584271.12	5357528.03	6580744.43	12214302.86	9751592.25	12623399.06	14422049.39	15782399.10	16670488.57
Total of energy Cost /year	658919001.82	642437311.99	607832044.27	543598702.75	525764742.86	528674232.57	525252831.64	510555788.95	509351984.70	490988660.17
Cost savings (kes) / year	0.00	16481689.83	51086957.55	115320299.07	133154258.96	130244769.25	133666170.18	148363212.87	149567017.12	167930341.65
Cost savings (euro) / year	0.00	138501.60	429302.16	969078.14	1118943.35	1094493.86	1123245.13	1246749.69	1256865.69	1411179.34

Day	11	12	13	14	15	16	17	18	19	20
%substitution	10.81	11.69	12.86	13.49	14.51	15.87	16.12	20.17	20.60	21.28
GJ of HFO Used	612.12	540.87	480.04	468.13	623.09	348.48	576.22	450.79	210.61	501.35
GJ of AF used	72.15	71.56	71.56	73.03	105.74	133.78	110.71	113.93	68.61	135.53
Total GJ	684.27	612.43	551.60	541.16	728.83	482.26	686.93	564.72	279.22	636.88
Hours of running dryer	24.00	22.12	18.88	17.93	22.32	14.88	20.82	18.75	8.93	20.25
GJ/hr of HFO	25.51	24.45	25.43	26.11	27.92	23.42	27.68	24.04	23.58	24.76
GJ/hr of AF	3.01	3.24	3.79	4.07	4.74	8.99	5.32	6.08	7.68	6.69
Total GJ/hr	28.51	27.69	29.22	30.18	32.65	32.41	32.99	30.12	31.27	31.45
GJ/day of HFO	612.12	586.84	610.22	626.61	669.99	562.06	664.23	577.01	566.03	594.19
GJ/day of AF	72.15	77.64	90.97	97.75	113.70	215.77	127.62	145.83	184.39	160.63
Total GJ/day	684.27	664.48	701.19	724.36	783.69	777.84	791.85	722.84	750.42	754.82
GJ/year of HFO	223423.80	214196.26	222730.42	228712.70	244546.08	205153.55	242444.15	210609.09	206600.63	216880.30
GJ/year of AF	26334.75	28339.31	33202.63	35680.02	41500.11	78757.58	46581.15	53228.10	67303.87	58629.27
Total GJ/Yr	249758.55	242535.57	255933.05	264392.73	286046.18	283911.13	289025.30	263837.18	273904.50	275509.57
Cost of HFO/Year	467626013.40	448312765.44	466174776.86	478695691.49	511834935.54	429386376.77	507435605.65	440804821.18	432415112.52	453930460.15
Cost of AF/Year	16380214.50	17627052.59	20652034.07	22192973.88	25813066.88	48987215.16	28973477.00	33107875.71	41863009.99	36467408.47
Total of energy Cost /year	484006227.90	465939818.03	486826810.93	500888665.37	537648002.42	478373591.94	536409082.65	473912696.90	474278122.51	490397868.62
Cost savings (kes) / year	174912773.92	192979183.79	172092190.89	158030336.45	121270999.40	180545409.88	122509919.17	185006304.92	184640879.31	168521133.20
Cost savings (euro) / year	1469855.24	1621673.81	1446152.86	1327986.02	1019084.03	1517188.32	1029495.12	1554674.83	1551604.03	1416143.98

Continuation Table 4.2: Actual Substitution Data

4.4.3: Projected and Actual Total Energy Cost per Year

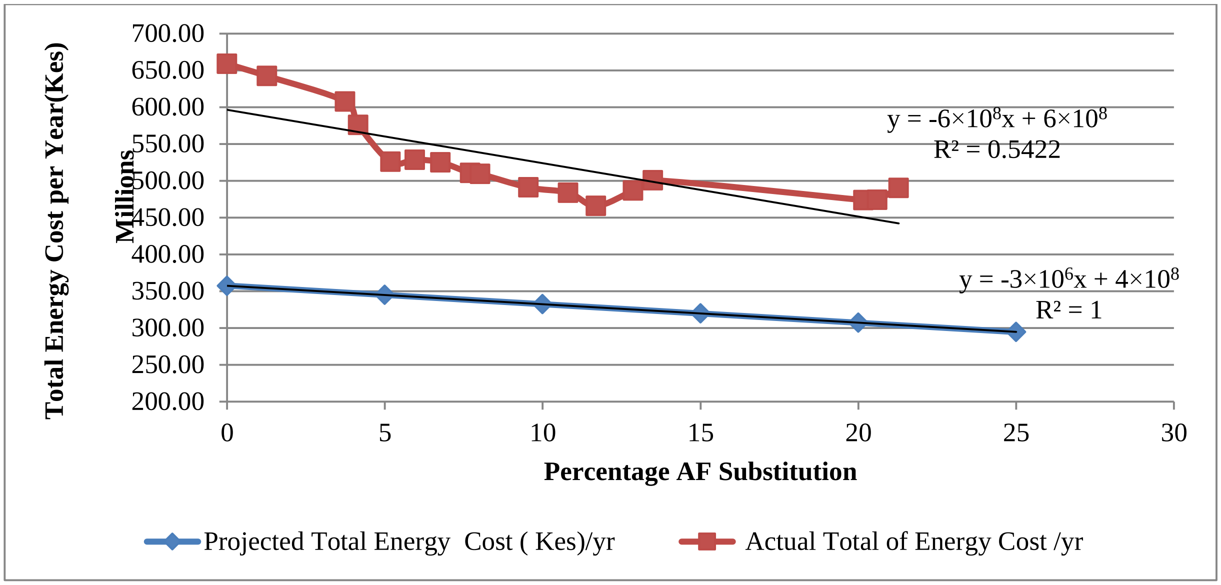

Figure 4.3: Projected and Actual Total Energy Cost per Year

From the projected substitution scenario in table 4.1 and figure 4.3 the total energy cost was decreasing with increase of AF substitution. This is because AF costs are lower than HFO and therefore energy mix cost cheaper than when only HFO is used. The relationship of total energy cost against percentage substitution is linear given by;

$y = -3\times10^6x + 4\times10^8$ (3)

Where;

y = total cost of energy/year in Kenya shillings

x = percentage of AF substitution.

The above equation can be rewritten as;

$Total\ energy\ cost/yr = -3\times10^6\%AF + 4\times10^8$ (4)

The degree of correlation of the total energy cost of energy and percentage AF substitution indicated by R^2 was 1 because this was an ideal scenario giving a perfect relation. On the other hand of actual substitution scenario the total energy cost per year was also decreasing with increase in percentage AF substitution as shown in table 4.2 and figure 4.3. This was because the energy mix used was cheaper as opposed to using only HFO for drying. There was a fairly strong correlation of the total energy cost of energy and percentage AF substitution indicated by R^2 of

0.5422. The curve was also not smooth because of technical errors during the operation of the dryer. The equation of the trend line of the total cost of energy against percentage AF substitution was linear given by;

$y = -6\times10^{8}x + 6\times10^{8}$ (5)

This implied that;

Total energy cost/yr $= -6\times10^{8}\%AF + 6\times10^{8}$ (6)

From the experimental results the actual total energy costs were higher than the projected total energy cost.

4.4.3 Projected and Actual HFO Cost per Year.

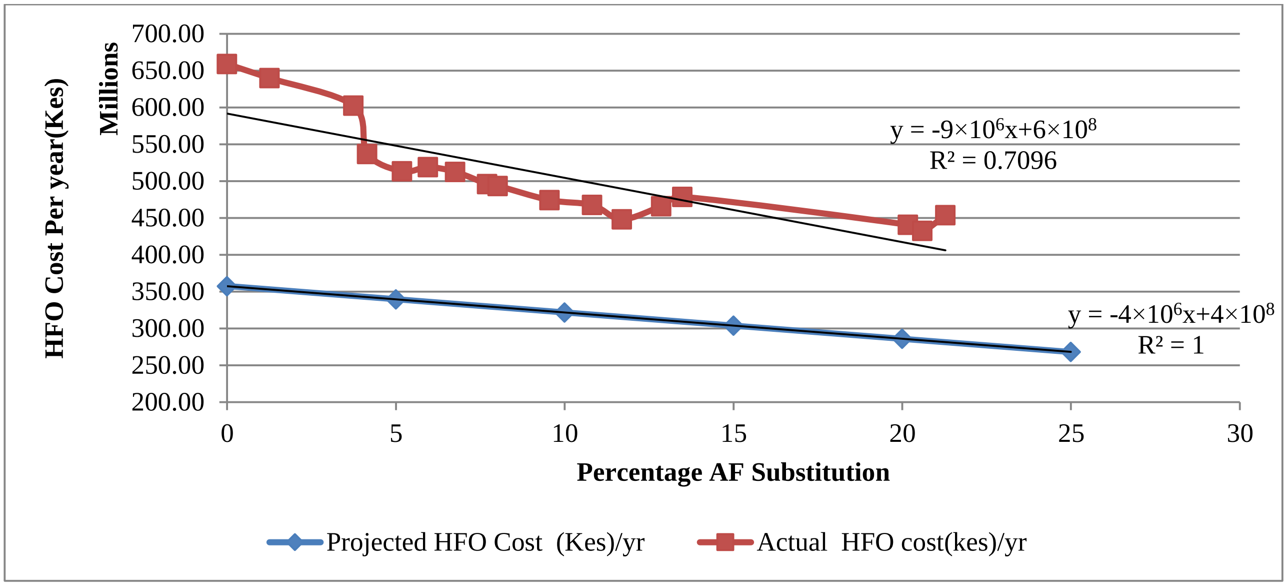

Figure 4.4: Projected and Actual HFO Cost Per Year

A comparison of projected HFO cost per year was done against actual HFO cost per year. From table 4.1 and figure 4.4 the cost of HFO was decreasing with increase of percentage AF substitution in both projected and actual substitution scenarios. The relationship for the projected substitution scenario was expressed as;

$y = -4\times10^{6}x+4\times10^{8}$. (7)

Equation 7 can be rewritten as;

HFO cost/yr $= -4\times10^{6}\%\ AF+4\times10^{8}$. (8)

The correlation coefficient of $R^2 = 1$ because this situation was a perfect scenario. The cost of HFO cost was decreasing because the cost of the energy mix was lower than the cost of using HFO only in the dryer.

From table 4.2 and figure 4.4 the actual cost of HFO was decreasing with increase of percentage substitution.There was a fairly strong linear corellation between the cost of HFO and percentage AF substitution with R^2 of 0.7096.The curve of cost of HFO per year against Percentage substitution was however not smooth because the scenario was real and therefore affected by the operating conditions. The equation for the trendline of the relationship between actual cost of HFO and percentage substitution was given by ;

$$y = -9\times10^6x+6\times10^8 \qquad (9)$$

Equation 9 was rewritten as;

$$HFO\ cost/yr= -9\times10^6\%AF+6\times10^8 \qquad (10)$$

4.4.4: Projected and Actual AF Cost

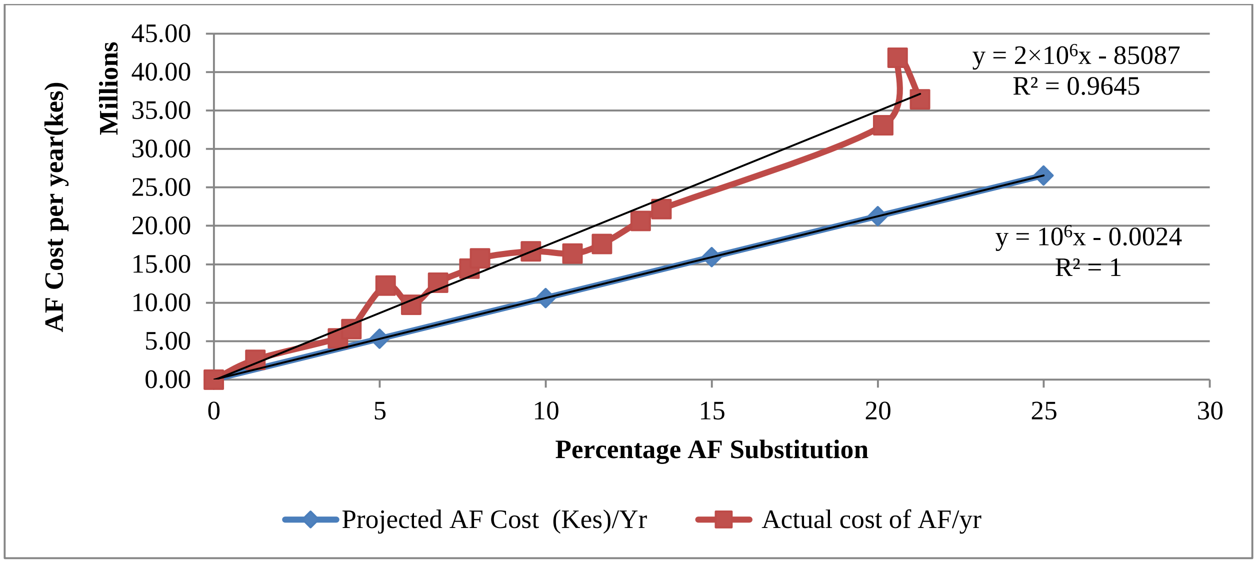

Figure 4.5: Projected and Actual AF Cost Per Year

For the projected substitution scenario from table 4.1 and figure 4.5 the cost of AF was increasing with increase of percentage AF substitution. The relationship was expressed as;

$$y = 1\times10^6x - 0.0024. \qquad (11)$$

This would further be expressed as;

$$AF\ cost/yr = 1\times10^6\%AF - 0.0024. \qquad (12)$$

The coefficient of correlation R^2 was 1 because the scenario was ideal. The slope graph was increasing because more AF fuel was used as the percentage AF substitution increased.

From Table 4.2 and figure 4.5 the actual cost of AF per year was increasing with increase in percentage AF substitution. This is because more AF was used with increasing percentage substitution. From figure 4.5 there was a strong linear correlation between actual cost of AF and percentage AF substitution with $R^2 = 0.9645$. However the curve was not smooth because substitution was real and therefore affected by the operating conditions of the system. The relationship of the actual substitution was expressed by a linear trend line of;

$$y = 2\times10^6x - 85087 \qquad (13)$$

This equation can further be expressed as;

$$AF\ cost/yr = 2\times10^6\%AF - 85087 \qquad (14)$$

4.4.5: Projected and Actual Savings per Year

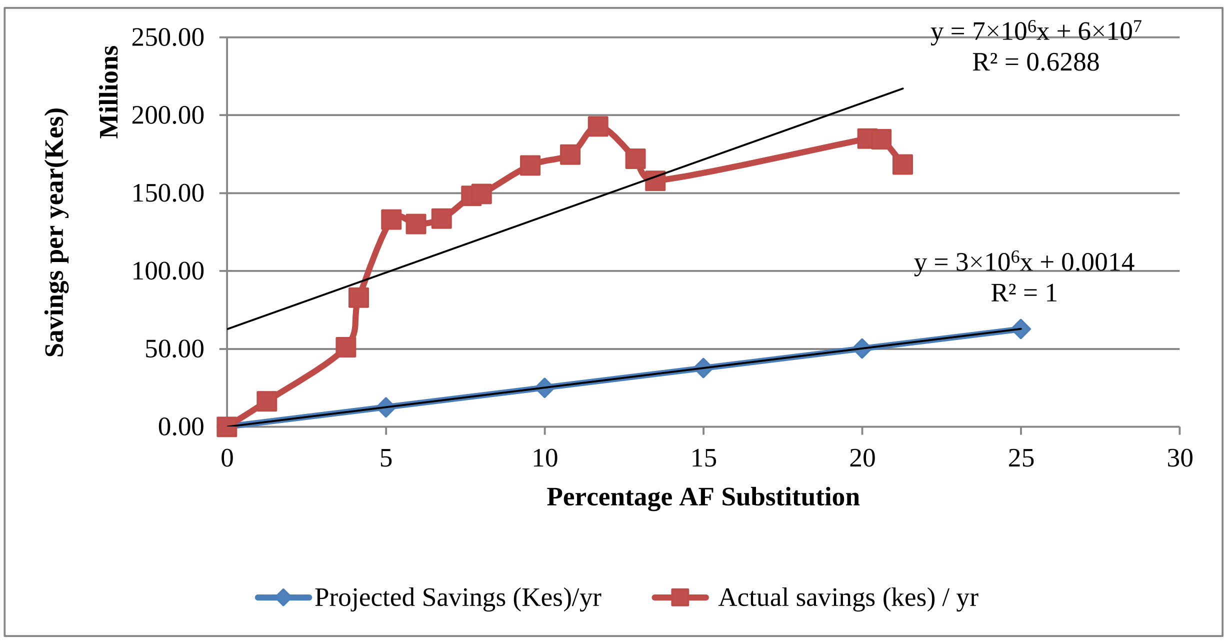

Figure 4.6: Projected and Actual Savings per Year

In the projected substitution from table 4.1 and figure 4.6 percentage savings were increasing with increase of percentage AF substitution. This was a linear relationship between percentage savings and percentage AF substitution expressed as;

$$y = 3\times10^{6}x + 0.0014 \quad (15)$$

This implied that;

$$Savings = 3\times10^{6}\ \%AF + 0.0014 \quad (16)$$

The coefficient of correlation of $R^2 = 1$ because the scenario was ideal. More savings were made with increase of percentage AF substitution because the energy mix was cheaper than using HFO only for drying. For the actual substitution scenario from table 4.2 and figure 4.6 the costs savings per year increased with increase of percentage substitution. This was because of the lower cost of the energy mix from HFO and AF. There was also fairly strong correlation of percentage savings and percentage AF substitution with $R^2 = 0.6288$.The curve was not smooth because substitution the experiment was a trial and we experienced technical problems such as clogging of hopper with rice husks. There was a linear trade line relationship of the percentage savings versus percentage AF substitution given by;

$$y = 7\times10^{6}x + 6\times10^{7}. \quad (17)$$

This implied that;

$$Savings = 7\times10^{6}\%\ AF + 6\times10^{7} \quad (18)$$

4.5 Economic Analysis

4.5.1: Cost Benefit Analysis

The cost of installing the pilot project was as indicated in table 4.3.

Table 4.3: Installation Cost Breakdown

Cost Breakdown	Amount(KES)
Steel structures material cost	372,000.00
Mechanical/Electrical Installation	469,918.00
Materials Cost(blower/electrical motor/rotary feeder/electrical cables/ panels & automation)	2,469,200.00
Trials(Labour & rice husks)	494,970.00
TOTAL	**3,806,088.00**

Source: Bamburi NGP, 2014

Table 4.4: Fuel Handling Cost

Rice husks	Monthly tonnage	Cost per ton (KES)	Transport cost/t to collection center,(KES)	Bagging, Handling cost/t, (KES)	Total cost per ton,(KES)
	200	6000	800	1500	8300
Total fuel handling cost					**1660000**

Source: Aquiline Distributors, 2013

The maintenance cost was assumed to be at 5% in the first and second year, doubling in the third year and three times in the fourth and fifth year of the initial maintenance cost. The discounting rate was at 10%.

Table 4.5: Cost Benefit Analysis

YEAR / COSTS	1	2	3	4	5
Installation costs	3,806,088.00	0.00	0.00	0.00	0.00
maintenance cost	190,304.00	190,304.00	380,608.00	570,912.00	570,912.00
fuel handling cost	1,660,000.00	1,660,000.00	1,660,000.00	1,660,000.00	1,660,000.00
Total cost per year	5,656,392.00	1,850,304.00	2,040,608.00	2,230,912.00	2,230,912.00
Benefits					
Fuel cost Reduction	0.00	25,122,151.63	25,122,151.63	25,122,151.63	25,122,151.63
Net Cash flow	-5,656,392.00	23,271,847.63	23,081,543.63	22,891,239.63	22,891,239.63
Discount rate	10%				
Discount factors	1.00	0.91	0.83	0.75	0.68
Discounted cash flows					
Total cost per year	5,656,392.00	1,683,776.64	1,693,704.64	1,673,184.00	1,517,020.16
Benefits per year	0.00	22,861,157.98	20,851,385.85	18,841,613.72	17,083,063.11
Net cash flow	-5,656,392.00	21,177,381.34	19,157,681.21	17,168,429.72	15,566,042.95
Cumulative	-5,656,392.00	15,520,989.34	34,678,670.56	51,847,100.28	67,413,143.23
NPV	KES 67,409,040.84				
IRR	4.10				

This analysis was done to establish the total costs incurred in the projects and the benefits to be gained from the implementation of the project to establish if the substitution was worthwhile. The analysis was done at a 10% alternative fuel substitution.Net present value and internal rate of return were calculated in order to take in to account the time value of money. This was done using the excel program.NPV is normally calculated as;

$$NPV = I_1 + \frac{I_2}{1+r} + \frac{I_3}{(1+r)^2} + \cdots + \frac{I_n}{(1+r)^n} \quad (19)$$

Where I's= cash flow for each year

The subscript = year number

r = the discount rate.

The internal rate of return is the interest rate that makes the Net Present Value zero.

$$0 = P_0 + P_1/(1 + IRR) + P_2/(1 + IRR)^2 + P_3/(1 + IRR)^3 + \ldots + P_n/(1 + IRR)^n \quad (20)$$

Where;

P_0, P_1, P_2, P_3…. P_n is the cash flows in periods 1, 2, 3. . . n, respectively; and IRR is the project's internal rate of return.

But from the excel function NPV was calculated as;

$$NPV = NPV(rate, value1, value2, \ldots) \quad (21)$$

And

$$IRR = IRR\ (Net\ cash\ flow\ at\ year\ 1{:}\ Net\ cash\ flow\ at\ year\ 5, 0.1) \quad (22)$$

The cash flows were discounted at 10 percent in order to cater for the risks associated with the project. From the analysis a positive net present value of 67,409,040.84 was realised which was an indicator that the substitution was worthwhile. IRR was calculated to be 4.10 %. This was the discount rate often that made the net present value of all cash flows from a the substitution project equal to zero. The internal rate of return was a rate quantity which was an indicator of the efficiency, quality and yield of an investment.

4.5.2: Effect of Substitution

Projected substitution data was used to establish the effect of substitution. A graph of total energy cost and cost of using HFO only were plotted against %AF substitution to establish the effect of substitution.

Table 4.6: Substitution Effect

DESCRIPTION	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
HFO Cost (Kes)	357491491.33	339616916.77	321742342.20	303867767.63	285993193.07	268118618.50	250244043.93	232369469.37	214494894.80	196620320.23	178745745.67
AF Cost (Kes)	0.00	5313498.75	10626997.50	15940496.25	21253995.01	26567493.76	31880992.51	37194491.26	42507990.01	47821488.76	53134987.51
Total Cost (Kes)	357491491.33	344930415.52	332369339.70	319808263.89	307247188.07	294686112.26	282125036.44	269563960.63	257002884.81	244441809.00	231880733.18
Savings (Kes)	0.00	12561075.82	25122151.63	37683227.45	50244303.26	62805379.08	75366454.89	87927530.71	100488606.52	113049682.34	125610758.15

DESCRIPTION	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
HFO Cost (Kes)	160871171.10	142996596.53	125122021.97	107247447.40	89372872.83	71498298.27	53623723.70	35749149.13	17874574.57	0.00
AF Cost (Kes)	58448486.26	63761985.02	69075483.77	74388982.52	79702481.27	85015980.02	90329478.77	95642977.52	100956476.27	106269975.03
Total Cost (Kes)	219319657.36	206758581.55	194197505.73	181636429.92	169075354.10	156514278.29	143953202.47	131392126.66	118831050.84	106269975.03
Savings (Kes)	138171834	150732910	163293986	175855061	188416137	200977213	213538289	226099365	238660440	251221516

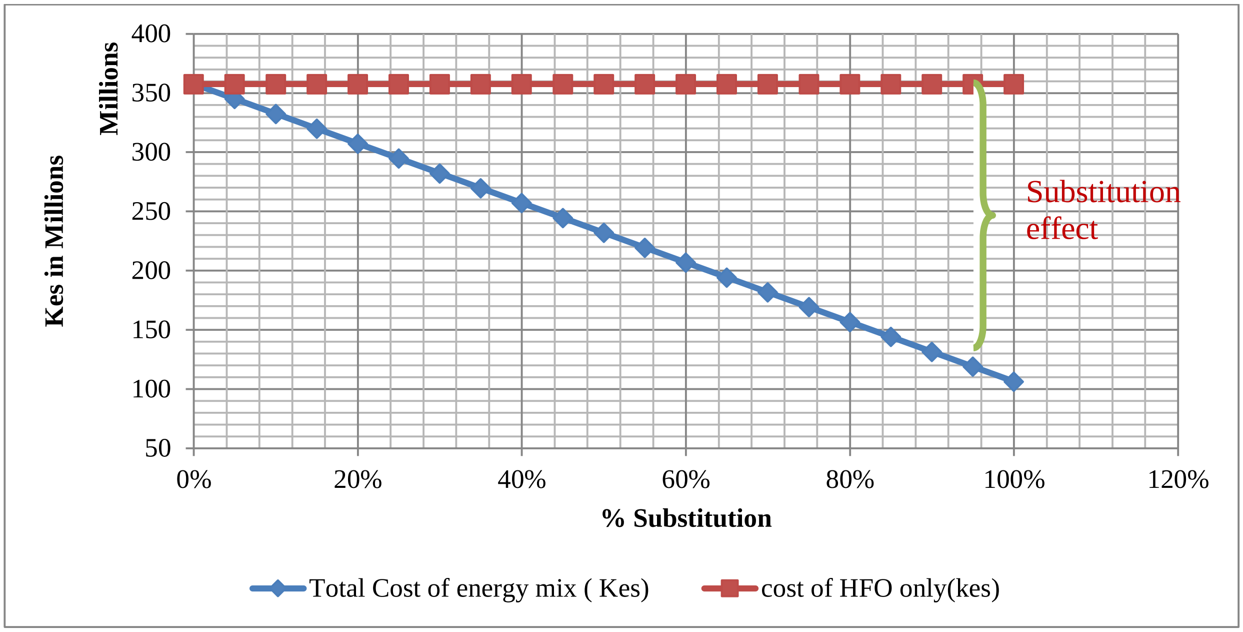

Figure 4.7: Substitution Effect

The substitution effect measures how much higher price encourages consumers to use other goods, assuming the same level of income. Table 4.6 Figure 4.7 substitution effect, shows a gradual cost drop of the energy used to dry pozzolana from 357491491.33 Kenya shillings with increasing percentage AF substituted to 106,269975.03 Kenya shillings when HFO is completely substituted by AF. This effect is caused by the relatively high cost of HFO that induces the use of more of a relatively lower priced energy i.e. AF and less on high priced HFO. This is due the rise the cost of fossil fuels. This is a positive scenario in economics, but the degree of substitution can only be justified by the availability of AF to completely substitute HFO and the efficiency of the dryer to run on AF alone. This is an area for further research to determine the efficiency of the dryer in relation to the percentage substitution with HFO.

4.5.3: Substitution Equilibria

This shows equilibria of different variables considered. In this case the equilibrium of total cost and savings, HFO cost and savings and HFO cost and AF cost.

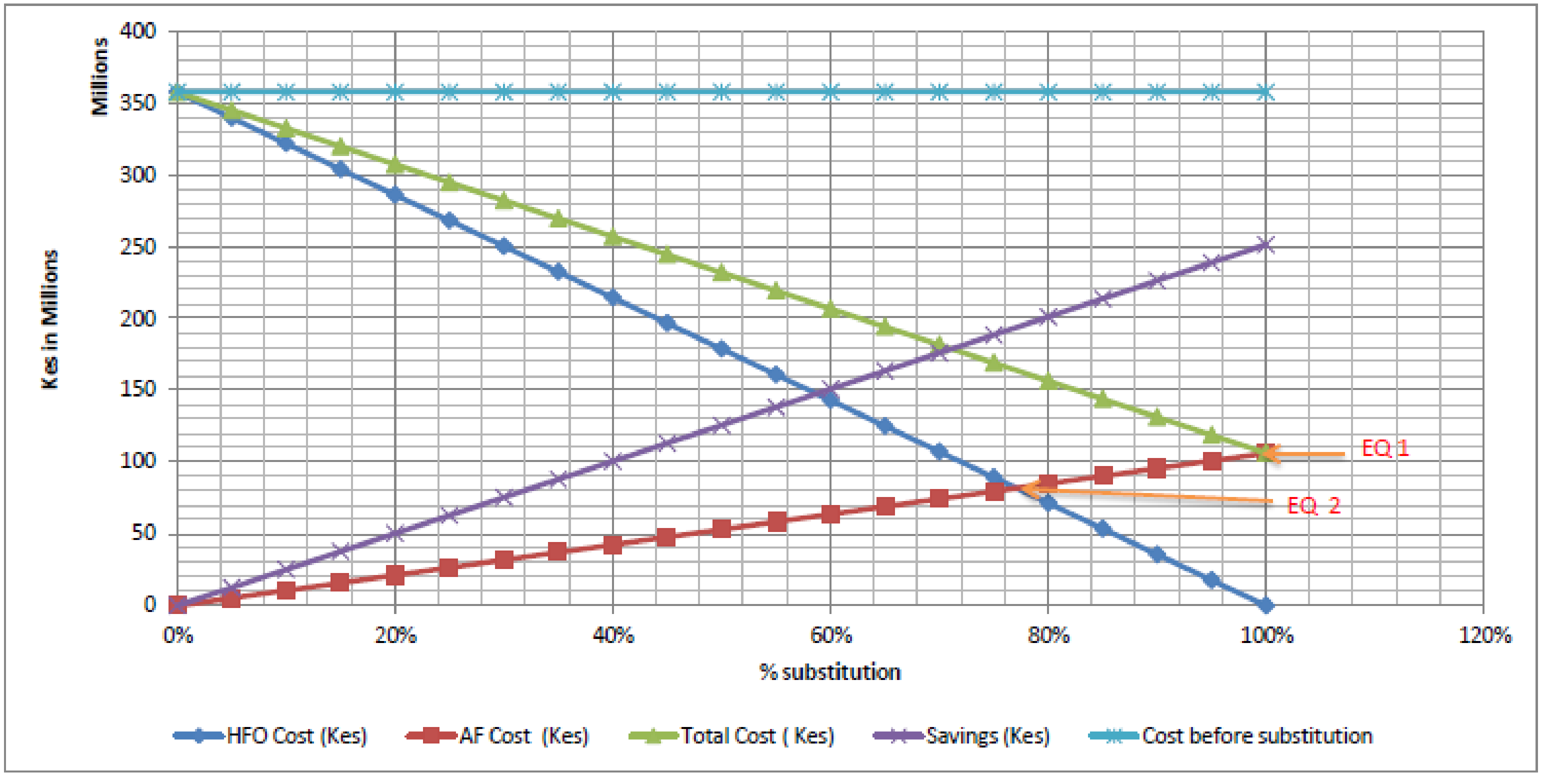

Figure 4.12: Substitution Equilibria

From figure 4.12 two points of equilibrium were discovered. Equilibrium 1 was the point where the total energy cost was equal to AF cost. This was realized at 100% where the total energy is derived from the AF. Equilibrium 2 was the point where the HFO cost was equal to AF cost. This was at 77%. The savings curve also cuts the curve of HFO cost and total cost at 58% and 70% respectively. This is because of the cost of AF used. Although the cost of energy and total cost of HFO reduces with increase in percentage substitution while savings increases with increase in percentage substitution further research is required to investigate other economic dynamics that may affect the substitution such as, AF fuel availability and efficiency of the system.

4.5.4: Operational Expenditure Analysis

Both simple payback period and return on investment were carried out to determine the viability of the investment. The analysis was carried out using the pilot substitution scenario with annual savings at 9.55% AF fuel substitution.

Table 4.7 Operational Expenditure

Pilot substitution project	
Capital invested	
Installation costs	3,806,088.00
fuel handling cost	1,660,000.00
Total cost per year	5,466,088.00
Annual savings at 10 % = 168000000 (From table 4.2)	

$$\text{Simple payback period} = \frac{\text{capital invested}}{\text{annual savings}}$$

$= \frac{5466088}{168000000}$ = 0.0325 years

= 0.39 months

= 12 days

$$\text{ROI} = \frac{\text{Gain from investment} - \text{cost of investment}}{\text{cost of investment}}$$

$$= \frac{168000000-5466088}{5466088} = 29.72\%$$

From the operational expenditure analysis simple payback period was 12 days and return on investment was 29.72%. The short payback period and high return on investment indicate that this project is of high yielding benefit to the investor. From the four capital budgeting techniques i.e. NPV, IRR, Simple payback period and ROI the investment was worthwhile to undertake.

4.5.5 Technical Analysis of the Project

The pilot project was soundly designed and engineered. It was observed that the AF fuel did not have any effect the quality of the processed cement. The professionals, technicians and workers on the ground were also able to handle the system without any further training.

CHAPTER FIVE: SUMMARY OF FINDINGS CONCLUSIONS AND RECOMMENDATIONS.

5.1 Introduction

The research project was to analyze the energy cost savings by substituting HFO with biomass for a pozzolana dryer. The study was carried out at Bamburi cement, Nairobi grinding plant in Athi River. The summary of these findings are discussed in this chapter in comparison with the main objectives that guided the research. The study had three objectives. This chapter presents the summary of the findings on the basis of the objectives to identify the implications and draw appropriate conclusions

5.2 Summary of Findings

The major findings of this study are summarized according to the research objectives. The first objective sought to study the existing system and analyze the fuel composition and consumption of the existing dryer. This was to determine the operating conditions of the existing dryer which were measured and represented in an energy and mass balance. The dryer used HFO at a mass flow rate of 2617kg/hr. only; the combustion air was at 31°C. Hot gases are generated at 930°C; pozzolana was dried from 22% moisture content to maximum of 2% moisture content and the outlet hot gasses are released to the atmosphere at 110°C.The first objective of the research also sought to study the pilot auxiliary system to handle biomass. The auxiliary system consisted of a blower run by a 30kw motor, venturi, rotary feeder run by a 20kw motor, and hopper of 2 tonne capacity and piping system of diameter of 150mmto the burner. The blower through centrifugal force propelled air forward, giving it some velocity. When the air reached the venturi there is pressure drop and increase of velocity of the air. At the same time rice husks flow down the hopper and discharged through the rotary feeder. They are then blown through the piping system into the burner where they are mixed with HFO. The rice husks were introduced at different percentages of substitution

The second objective of the research was to compare the projected substitution scenario with actual substitution. From the research findings of the projected substitution cost, the total energy cost was reducing with increase in percentage AF substitution and HFO cost was also was reducing with an increase in percentage AF substitution. Again AF cost was increasing with increase in percentage AF substitution and cost savings were increasing with increase in percentage AF substitution. The coefficient of correlation (R^2) of total energy cost, cost of HFO, and cost of AF and savings with a percentage of AF substitution was 1. These graphs were straight line graphs because the forecast was ideal. However, from real substitution carried out, the total energy cost and HFO cost were reduced with an increase in percentage AF substitution. Again AF cost and savings were increasing with increase in percentage AF substitution. The coefficient of correlation (R^2) of total energy cost, HFO cost, AF cost and savings with the percentage AF substitution were 0.5422, 0.7096, 0.9645 and 0.5288 respectively. These graphs were not smooth graphs because the forecast was real and affected by environmental conditions.

The third objective of the research was to carry out the economic analysis of the new system in order decide on the viability of the project. From the cost benefit analysis a positive net present value of 67,409,040.84 was realized which was an indicator that the substitution was worthwhile. The IRR was calculated to be 4.10%. Again the simple payback period was 12 days and return on investment was 29.72%. Using these four techniques of capital budgeting i.e. NPV, IRR, Simple payback period and ROI the investment was worthwhile to undertake.

Further on economic analysis substitution effect and substitution equilibria was carried out. On the substitution effect, there was gradual cost drop of the energy used to dry pozzolana from 357491491.33 Kenya shillings with increasing percentage AF substituted to 106,269975.03 Kenya shillings when HFO is completely substituted by AF. This effect was caused by the relatively high cost of HFO that induced the use of more of a relatively lower priced energy i.e. AF and less on high priced HFO. Again two points of equilibrium were discovered. Equilibrium 1 was the point where the total energy cost was equal to AF cost. This was realized at 100% where the total energy was derived from the AF. Equilibrium 2 was the point where the HFO cost was equal to AF cost. This was at 77%. The savings curve also cuts the curve of HFO cost and total cost at 58% and 70% respectively. This is because of the low cost AF used. Although the cost of energy and total cost of HFO reduced with increase in percentage substitution while savings increase with increase in percentage substitution further research is required to investigate other economic dynamics that may affect the substitution such as, AF fuel availability and efficiency of the system.

5.3 Conclusions

From the findings reported in this study, several conclusions can be made regarding the substitution of HFO with biomass in a pozzolana dryer. First Substitution led to a reduction of the cost of energy used and therefore savings, increased with the increase of percentage substitution. Secondly, using the four techniques of capital budgeting, i.e. NPV, IRR, Simple payback period and ROI the investment was worthwhile to undertake. Lastly the pilot project was soundly designed and it was observed that the AF fuel did not have any effect the quality of the processed cement. The professionals, technicians and workers on the ground were also able to handle the system without any further training.

5.4 Recommendations

Several challenges were encountered. These included; slow hopper feeding, big particles in the rice husks which sometimes blocked the hopper, too much dust from the rice husks and absence of feeder monitor However in view of the findings and conclusions made, the study makes several recommendations. First, the study makes that the investment is worthwhile to undertake when the challenges faced have been addressed i.e. installation of the substitution system with a vibrator in the hopper feeding, installing a mesh from the AF source, installing a scrubber from the AF source, installation of a speed monitor, installation of a conveyor belt to convey the AF materials and synchronising the substitution system with the enter milling system by automating the system.

The second set of recommendations touches on areas for future research. The findings present some interesting areas for future research. Researchers need to investigate further and determine the efficiency of the dryer in relation to the percentage substitution with HFO to determine the maximum efficiency and the implication of the various points of equilibria in the study. Future research can expand on substitution in relation on capital and labour employed and establish the percent savings per unit of cement produced.

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