OPEN AIR DRYING OF BAGASSE - POTENTIAL IN SUGAR INDUSTRIES
(CASE STUDY: MUMIAS SUGAR COMPANY)

BY

OPERE JOEL AKOMO

F56/64951/2010

A project report submitted to the University of Nairobi in partial fulfillment of the requirements for the Degree of Master of Science in Energy Management in the Department of Mechanical and Manufacturing Engineering.

2016

DECLARATION

I, Opere Joel Akomo declare that this thesis is my original work and has not been presented for a degree in another University or for any other award.

Opere Joel Akomo

Department of Mechanical and Manufacturing Engineering.

Signature………………………………………………….. Date…………………………………

This thesis is submitted for examination with our approval as the University supervisors:

Dr. Alex A. Aganda

Department of Mechanical and Manufacturing Engineering.

Signature………………………………………………….. Date…………………………………

Prof. James Nyang'aya

Department of Mechanical and Manufacturing Engineering.

Signature………………………………………………….. Date…………………………………

DEDICATION

To my late father Chief Elizaphan Opere who sacrificed his resources and energy to ensure quality holistic education to his children and the people of Suba Constituency.

ACKNOWLEDGMENT

I acknowledge first and foremost the Almighty God who is the beginning of knowledge and all understanding. (Proverbs 1:7). My heartfelt appreciation also goes to my parents and special friends for the unwavering support and encouragement.

To my supervisors, Dr. Alex Aganda and Prof. J.A. Nyang'aya, who have each spent incredible time to give me technical and academic advice in this journey, my sincere gratitude goes to them.

I would also give special appreciation to Engineers Jeremiah Oyoo, Gwara and Evans Ochieng' of Mumias Sugar Company for their massive support. There were also other staff members of Mumias Sugar Company at the workshop, cogeneration plant and agronomy, whom without their steadfast support and words of encouragement this project may have taken longer and therefore I collectively recognize and acknowledge them.

Lastly my appreciation goes to my senior Eng. Nzuka, my colleagues and friends at my workplace for their selfless support and encouragement.

ABSTRACT

Biomass feed stock like wood chippings, rice husks and sugarcane bagasse once considered waste are now looked upon as viable fuel sources. Bagasse, a byproduct of sugar cane crushing and leaching, is used in sugar industries to generate high pressure and temperature steam in the boilers for generating electricity which is then utilized internally in the factories and also exported to the grid. In most instances, the bagasse as used directly from the mills contains about 50% moisture as is the case in Mumias Sugar Company (MSC). However, for more efficient utilization, further drying through methods such as flue gas drying, exit steam drying and open air drying to lower its moisture content is useful in increasing its calorific value

This study was done to assess the potential of open air drying of bagasse and the resulting improvements in its combustion. The main stages of the study included the design of the drier, determination of the calorific value of dried bagasse and the effect on combustion. Two dryers were fabricated for drying of bagasse. One had a steel cover and the other a glass cover

The following parameters were monitored during drying , relative humidity (RH), temperature (T), Solar Insolation (W/m^2) and moisture content (%).

The results revealed that open air drying reduced the moisture content of bagasse by about 4% - 6% in 3-4 hours of drying in a day. The gross calorific value of the dried bagasse also increased considerably from 9514kJ/kg at 50% moisture content to 11343.7kJ/kg at 40.05% moisture and to 18103kJ/kg at 5.4% moisture content on the third day of continuous drying.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

°C – degrees Celcius

cogen - cogeneration

COMESA - Common Market for Eastern and Southern Africa

DSD – direct type solar drying

FIT - feed-in-tariff

g – grams

GCV – gross calorific value

GOK – Government of Kenya

GW – gigawatts

GWEC - Global Wind Energy Council

GWh – gigawatt-hour

H – hours (24 – hour)

hr(s) - hour(s)

IPP – independent power producers.

ISD – Indirect type solar drying

KenGen - Kenya Electricity Generating Company Limited

kg – kilogram

KIPPRA - Kenya Institute for Public Policy Research and Analysis

kJ/kg – kilojoules per kilogram

KPLC – Kenya Power and Lighting Company

kV – kilovolts

kW – kilowatt

kWh – kilowatt-hour

kWh/kg – kilowatt-hours per kilogram

kWh/m^2 – kilowatt-hours per square meter

LPG – Liquefied Petroleum Gas

M_c – critical moisture content

MDGs - Millennium Development Goals

MESC - Ministry of Economic and Social Council

MJ – megajoules

MoPND - Ministry of Planning and Development

MSC – Mumias Sugar Company

MW – megawatts

NCV – net calorific value

PV – photovoltaic

RES - renewable energy resources

RH – relative humidity

SADC - Southern Africa Development Corporation

SREP - Scaling-up Renewable Energy Program

TA – turbo alternators

VOC - volatile organic compound

w.b. – water base

W/m^2 – watts per square meter

Wh – watt-hour

CHAPTER ONE: INTRODUCTION.

Availability of affordable energy has a critical role in the achievement of development objectives. The level and intensity of use of commercial energy is a fundamental indicator of the degree of economic growth and development. When incomes increase and urbanization intensifies, household and industrial demand for energy also increases and necessitates a greater emphasis on the sector.

In Kenya wood fuel accounts for 68% of the total primary energy consumption primarily for rural populations and urban poor .The commercial sector is dominated by the petroleum and hydro-electricity as the prime movers accounting for 22% and 9% respectively while others like coal account for less than 1%. Electricity remains the preferred form of energy in the society and access to it is normally associated with rising of high quality of life (Ministry of Planning and Development (MoPND) & Ministry of Economic and Social Council (MESC), 2007).

1.0 Background

Kenya is endowed with various renewable sources of energy such as wind, geothermal, solar, hydroelectricity, biomass, bio-fuels and the recently discovered fossil fuels. This has however not been enough to satisfy the energy demands of the country as a whole. The Country's demand for electricity stands at 1236MW against an installed capacity of 1691MW from which 52% is obtained from hydroelectric power, 30% thermal power, 17.7% geothermal power and about 0.01% from wind power generation. The peak load is however projected to grow to about 2500MW by the year 2015(Ministry of Energy, GOK, 2012).

The Country's dependency on hydroelectric power has however continued to be a problem because of the unpredictable and seasonal weather patterns. Kenya therefore continues to be insecure in its energy capacity provision and management as the water level in dams which feed hydropower stations continues to decrease. This has therefore necessitated the installation of expensive thermal power generations through independent power producers (IPPs) for both standing and base load generation (Ministry of Energy, GOK, 2012)

The constant and unpredictable changes in the cost of petroleum products for thermal generation and industrial consumption has also made the consumer vulnerable as the cost is transferred to them. Indeed the cost of electricity in Kenya is about four times that in South Africa and Egypt, the country's main competitors in the Southern Africa Development Corporation (SADC) and Common Market for Eastern and Southern Africa (COMESA) regions (Kenya Institute for Public Policy Research and Analysis, 2009). This makes the country to be less conducive for investment hence many investors opt for the other destinations where energy cost is lower.

In order to address these challenges, the government through the sessional paper no. 4 of 2004, the energy act of 2006 and the feed-in-tariff (FIT) policy (Ministry of Energy, 2012) laid down procedures for promoting electricity generation and utilization of renewable energy resources (RES) and a green energy fund facility under the national task force and accelerated development of green energy. The act also laid ground for partnership with the Independent Power Producers (IPPs.) The renewable energy sources identified for exploitation included wind, geothermal, solar, small hydro, nuclear and biomass.

1.1.1 Wind

This is a renewable source of electric power produced from converting the kinetic energy of moving air into electricity. It is a relatively cheap source of renewable energy compared to other sources for example, solar and geothermal as it costs about four times less per watt compared to photovoltaic installations and operate longer hours of about 12-16hrs compared to 5-6 hours for photovoltaic (PV) systems (Kenya Institute for Public Policy Research and Analysis, 2009).

Globally wind power generation has increased steadily since 1990's and the installed capacity in 2012 stood at 282GW up from 44GW (Global Wind Energy Council (GWEC), 2013). Kenya lies on the equator where wind speeds are typically low compared to higher latitude regions, though high wind speeds of 346 m/s^2 have been registered in some parts of Nairobi, Rift Valley, Eastern, North Eastern and Coast Province (Ministry of Energy, GOK, 2012)

The country currently has an installed windmill capacity of 5.5MW operated by Kenya Electricity Generating Company Limited (KenGen) at Ngong Hills. This was commissioned in August 2009. The first phase installation at Ngong which was later decommissioned was composed of two wind turbines of 0.15MW and 0.2MW. Studies by KenGen show that Ngong site can generate about 149GWh every year up from the 5.1MW wind farm (KenGen, 2012). The power generated here is directly connected to the 66kV distribution network grid within Nairobi. A one-wind generator was installed in Marsabit and was generating 200kW power before it was decommissioned in 2006 and replaced with two wind turbines of 250kW each at a cost of Kshs 198 million. (KPLC, 2012)

The government has of recent been promoting investment in the sector and through the Feed in Tarrif (FIT) policy has been providing a fixed tariff not exceeding US cents 12.0 per kWh of electrical energy supplied in bulk to the grid operator at the interconnection point (Government of Kenya, 2011). Of greater impact is the recently launched 300MW wind power project in Turkana. This sector however has not been fully exploited due to under-investment in the sector and the variations in wind pattern due to changes in seasons and weather.

1.1.2 Geothermal

Geothermal energy power is the natural heat from the earth's crust. It causes the water stored under the earth's crust to heat up to very high temperatures. It is usually extracted by drilling deep wells into the earth's crust to tap the steam that is at very high temperatures and pressures. The steam is then led through pipes to turbines. Kenya has an estimated geothermal energy potential of between 7000MW to 10,000MW spread over 14 prospective sites in the Rift Valley (SREP, GOK, 2011).

Currently the Country has an installed geothermal capacity of 480 MW with 308MW operated by KenGen and 78MW by independent power producer Orpower 4 both in the Olkaria Block. An additional 280MW was commissioned in 2015. Drilling is also on going for the 400MW for the Menengai field Phase One. Other areas being targeted include the Bogoria-Silali Block. Geothermal power has the advantages of not being affected by drought and climatic variability.it has no adverse effects on the environment and is readily available with no reliability on import fuel hence it is one of the most suitable source for the base load electricity generation in the country.

1.1.3 Solar

Kenya receives insolation of 4.6 kWh/m^2 due to the position of the country along the equator. The solar utilization is however low and is mainly through PV systems, drying and water heating. The solar PV systems are mainly for telecommunication, cathodic protection of pipeline, lighting and water pumping. The use of solar as a source of power is suitable for small institutions such as primary and secondary schools, dispensaries, health centres, police and administration units in arid and semi-arid lands where there is no access to the grids and is most suitable option for rural electrification (Energy Regulatory Commission, 2011).

There are however many challenges in using solar power including lack of suitable means of energy storage. There is usually solar power readily available as long as there is sunlight. The government has therefore, through the solar water heating regulations, sought to mitigate the challenges faced in exploring the solar energy source.

1.1.4 Small hydros

Kenya has five major basins which host the bulk of installed hydro power. These are Lake Victoria basin (295MW), Rift Valley basin (345MW), Athi River basin (84MW), Tana River basin (570MW) and Ewaso Ngiro North River basin (146MW) (Energy Regulatory Commision, 2011). There is however a greater potential for small, mini and micro-hydro system with capacities less than 10MW each (Government of Kenya, 2011). The installed capacity however is about 15.3MW to the grid. There is however the potential to generate more and the government through partnership with private and community generating groups is aiming to additionally add 22MW.

1.1.5 Nuclear Power Plant

Though considered a potentially long term option for electricity generation for the country, the technology is yet to be exploited. The country however has a task force in place and is projecting to have a nuclear plant functional from the year 2022 as a result of the long lead time associated with the development of conventional nuclear power plant.

1.1.6 Biomass

Biomass contribution to Kenya's final energy demand is around 70% providing greater than 85% of rural household energy needs, with the major source of biomass fuel being charcoal, wood fuel and agricultural waste such as sugarcane bagasse (Government of Kenya, 2011). It has become necessary to further explore and exploit the substantial potential areas, for example in sugar industries, through burning of bagasse in boiler for cogeneration.

Sugarcane is a major commercially grown agricultural crop in the vast majority of Western Kenya. It is one of the plants having the highest bio conversion efficiency of capture of sunlight through photosynthesis. With the ability to fix approximately 55 tons of dry matter per hectare of land under it, on annual renewable basis, it is important crop as a source of renewable power. The production of electrical energy in the sugar industries cogenerations is from sugarcane bagasse.

Bagasse is a fibrous material that is the main by-product of a cane sugar manufacturing plant, obtained after the sugar juice is leached out of the sugar cane .It represents 12% of the total sugar mass. Normally on leaving the mill, it has a high moisture content of around 50%. The fuel bagasse is taken directly to the boilers for firing to produce process steam and electricity through cogeneration systems. The electricity generated is consumed by the plant and the surplus is sold off to the national grid. Excess bagasse is stored for later use and without any attempt on further drying.

Reduction of the moisture content of bagasse is a preferred method for improvement of the combustion process and hence the boiler efficiency and reduction of stack emissions

1.2 Problem Statement

Bagasse, the by product from the cane sugar, is a fuel used for cogeneration in Mumias Sugar factory plant to produce electric energy to meet its process steam and in house power requirements. The bagasse used from the mills has a high moisture content of 50% with a gross heating value of 9514kJ/kg compared to bone-dried bagasse of 19268kJ/kg.

To burn the bagasse of 50% moisture content in the boilers, a lot of energy is required which is wasteful compared to burning dried bagasse which gives better combustion and results in less emission of stack gases. It is therefore necessary to explore bagasse drying methods like simple open air drying, which is cheaper and cost effective.

1.3 Objectives

1.3.1 Overall objective

Review of methods and benefits of drying of bagasse in sugarcane processing industry.

1.3.2 Specific Objectives

The specific objectives of the project are:

a) To assess bagasse utilization at a sugar cane factory.
b) To review bagasse drying methods at Mumias Sugar Company.
c) To determine the rate of drying of bagasse using open air drying.

1.4 Rationale

Recent discoveries of crude oil deposits in Kenya has not translated to production and availabilitry in the market and the country continues to be dependent on imported petroleum. Crude oil and other fossil fuel importation still accounts for 90% of total commercial energy use. This impacts negatively on the economy due to foreign exchange loss and also to high cost of goods and services.

The country however has other energy sources which could be exploited to make the country energy secure. Sugarcane bagasse which is a byproduct of cane sugar manufacturing plant is one such source. After milling, it is transported through conveyor belts for burning as fuel in the boilers and cogeneration plants. The electrical power produced at the steam turbines is used for the company's utilities and excess sold to the grid. The power generation can be enhanced if the moisture content of the bagasse is lowered to improve the combustion and boiler efficiency.

This project aims at addressing the issues of bagasse drying in sugar industries, the assessment of the viability and sustainability of the process in sugar industries with Mumias Sugar factory in Western Kenya as the case study. The company has a crushing capacity of 8000 tons and generates 36 MW of electricity through cogeneration out of which it exports 26 MW to the national grid.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction.

Bagasse, the fibrous material of sugarcane, is one of the main by-products of cane sugar manufacturing plants obtained after the sugar juice has been extracted from the sugarcane. It is used as one of the primary fuels for the boilers in the production of electrical energy. The cogeneration energy obtained is partially used by the industry and excess is sold to the grid. The bagasse usually has the moisture content of around 50-52% as it leaves the milling process (Yarnal & Puranik, 2010).

Experimentally it has been shown that bagasse with 50% moisture before drying and 35% moisture content after drying has gross calorific values (GCV) of 9456 kJ/kg and 12386 kJ/ kg respectively (Barroso, Barreras, Amaveda, & Lozano, 2003; Ghosh, 2003) . Much research on various drying processes using flue gases and steam has been carried out. However limited study has been carried out on the open air solar drying especially where there exists abundant solar energy like at MSC.

This project proposes to carry out an in depth study on solar drying of bagasse in a typical sugar industry. The relative humidity parameters, the temperature of the bagasse dryer and the solar insolation will be used to ascertain the rate of drying of bagasse.

2.1 Bagasse.

Bagasse is the fibrous residue of the cane stalk left, after crushing and extraction of the juice, which consists of fibers, water and relatively small quantities of soluble solids, mostly sugar (Paturau, 1988).

Bagasse can be defined as the solid fibrous material which leaves the delivery opening of the last mill of the tandem, after extraction of the juice (Hugot, 1986).

“Megasse” on the other hand, is the term used to refer to the pulp remaining after the extraction of juice from sugarcane or similar plants and is used as fuel and for making paper etc.The term “Megasse” and “Bagasse” are used interchangeably but in the present study megasse refers to the unleached by-product of the crushed cane from the diffuser to the mills.

2.2 Progress towards Bagasse Fuel

Limited scholarly publication existed during the period from 1910 to 1970. This could be attributed to the low cost of fossil fuels during this period. The economic recession that arose in the 1970’s, along with the energy crisis of that time prohibited interest on bagasse drying to reduce moisture content using flue gases. The dried biomass fuel improves combustion efficiency, increases steam production and reduces net air emissions and improve boiler combustion from about 65% to 70% and decreasing stack particulate and carbon dioxide emissions [Juan et al, Juan ,Arnao, 2004.]

Kerr (1976; Kerr & Nadler, 1911) studied the drying of the sugar cane bagasse using the exit gases of the boiler in 1910. The dryer made of steel was 1.2m x 1.8m cross section and 6.0m high. It was a counter current contact and equipped with deflectors to promote better gas – solid contact. The drier reduced the moisture content from 54.3% to 46.4% water base (w.b.) raising the steam production from 1.63 to 2.53 kilograms of steam per kilogram of bagasse.

Downing et al (Downing, Hobson, Kent, & Burbidge, 2002) investigated the potential of mechanical dewatering of bagasse and came to the conclusion that it is limited to approximately

40% moisture as the mills rarely perform to the limit and so forty-three percent moisture content would be an excellent performance. Kinoshita (Kinoshita, 1989) published four systems using boiler flue gases to dry bagasse out of which three of the four installations were rotary dryers and the other a flash dryer.

Feasibility study of bagasse pre-drying with waste stack gases by Farines (Farines, 1976) during the fuel crisis of 1972-73 including three rotary-drum type dryers of maximum capacity to operate with existing boilers, based on flue gases of temperature 218°C lowered the moisture content from 54% to 46% w.b. The effect was that the fuel oil consumption in 1976 was 1.01 gallons per ton (gal/ton) of cane, as compared to an average of 1.62 during the previous two years, showing an average saving of 0.61 gal/ton of cane (Farines, 1976).

In an in depth study, Correia (Correia, 1983) described the use of a pneumatic transport dryer and its advantages over the rotary in steam production of 16% by drying the bagasse from 52% to 40% moisture (w.b.) according to the experiment at Santo Antonio, in Alagoas, Brazil. Further experiments in Cruz Alta Sugar Industry after new installations in Olimpia City, Sao Paolo States, Brazil produced concurring data (Sánchez Prieto, Carril, & Nebra, 2001).

Nebra and Macedo (Nebra & Macedo, 1989) published an industrial equipment of a flash dryer that could work with 25 tonnes of bagasse . This is the biggest flash dryer reported so far that was developed by the centers de Technologia Copersucar, Brazil. Massarani and Valença (Massarani & Valença, 1981, 1983) did intensive study of bagasse drying in a moving bed dryer by developing a study from a laboratory scale to pilot one. The pilot one had a dryer of 0.40 x 0.50 x 2m out of which they obtained positive results.

Arrascaeta et al (Arrascaeta & Friedman, 1987) designed and obtained a patent for a bagasse dryer that elutriates the bagasse, separating the particles in different sizes. The design used both fluidized and pneumatic conceptions. Meirelles (Meirelles, 1984) studied drying of the wet bagasse in a fluidized bed dryer and observed that due to the cohesive characteristic of bagasse it was necessary to use a mixer to allow for fluidization. By removing the moisture, the agglomeration decreases and dried particles elutriated.

Salermo and Santaa (Salermo & Santana, 1986) designed and manufactured a dryer consisting of a fluidized bed, a preumatic duct and a cyclone. The dryer worked with 10 tons per hour (t/h) of 47% moisture content in wet bagasse while the final moisture content was 35% in wet bagasse using an inlet gas temperature of 250^0C . Barbosa (Barbosa, 1992) studied the kinetics of sugar cane bagasse drying in a flash dryer and observed that the major part of moisture reduction occurred in the acceleration zone.

Carolyn Roos, (Roos, 2008) conducted an in-depth study of Biomass drying and dewatering for clean heat and power reported an increase in boiler efficiency of as high as about 80% and corresponding steam production from around 50% to 60% when dry (biomass) are used due to improved combustion. Abdel-Rehim and Nagib (Abdel-Rehim & Nagib, 2007) in another experimental study reported that in solar drying of bagasse pulp, the drying time depends on the thermal and physical properties of the bagasse pulp and also on the climatic conditions (solar radiation, relative humidity, ambient temperature and wind speed).

In energy analysis of bagasse drying, Vijayaraj et al (Vijayaraj, Saravanan, & Renganarayanan, 2006) reported that the variation in energy requirement conditions to dry bagasse of 30% from 1.07 to 1.49 kWh/kg and the variations in energy utilization ration and the exergic efficiency from 37.99 to 8.33% and 14.52 to 75.41%. Cárdenas et al (Cárdenas, Devazquez, & Wittwer, 1994) also while analyzing the energetic and exergic efficiencies of boiler dryer system of a pneumatic dryer concluded that the use of a dryer improves the boiler efficiency.

2.3 Bagasse Generation Process

This process is illustrated in figure 2-1. After sugarcane has been harvested and transported to the mill yards, it is loaded into the crushing bays where through conveyors the cane is led into the heavy duty cutters chamber where the cane is crushed. The crushing process breaks up the hard rods of the cane and flattens the stems.

The crushed stems are passed through yet another crusher where they are crushed into smaller particles for maximum leaching of the sugars. These crushed particles or pieces are then fed into the diffuser where, with the help of imbibition water, the juice is extracted and collected into tanks for further process boiling to production of sugar crystals.

On the other hand, the megasse is transported from the diffuser through slat conveyors to the two sets heavy duty mills. In the first mill, the megasse is squeezed through the high pressure mills and the juice extracted is further collected into the storage tank. Because at this point the megasse from mill one still has a considerable amount of water, it is passed through mill two for further extraction. The juice is also collected into the storage tank and then pumped to the major storage tank in the diffuser.

The product out of mill two is therefore no longer megasse but bagasse and is transported through conveyor belt for use in the boilers and cogeneration plant. The bagasse at this point has about 45% – 50% moisture content and has a heating value of up to about 4.22 MJ

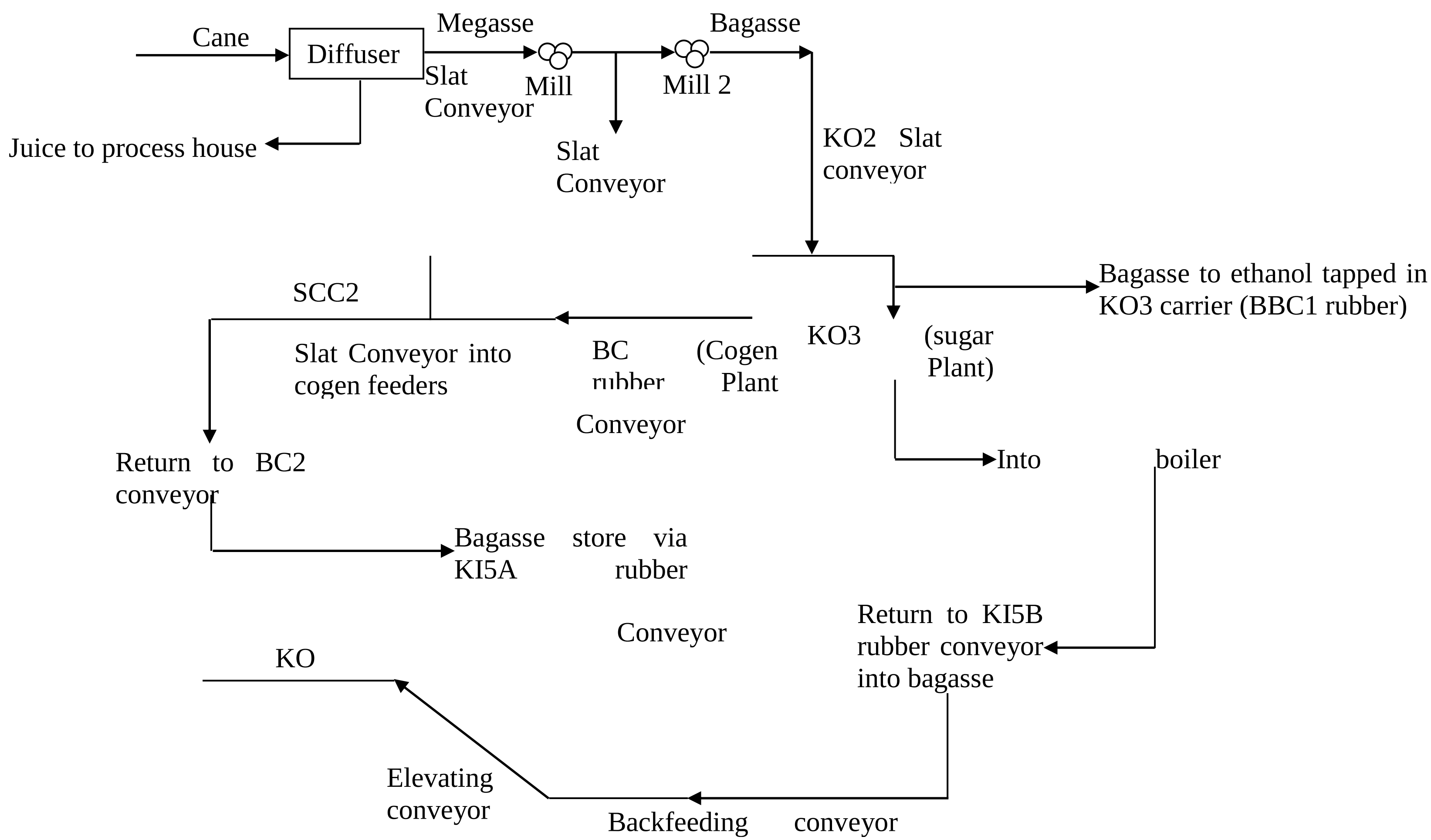

Figure 2. 1: The Bagasse Generation Process.

2.3.1 Bagasse Properties

Bagasse being the fibrous residue of the cane stalks after crushing consists of a mixture of hard fibre, with soft and smooth parenchymatons (prit) tissue with high hygroscopic property. It made up mainly of cellulose, hemicellulose, pentosans, lignin, sugars, wax and minerals. Its final composition after milling however depends on method of harvesting as well as age and type of cane.

On average it is assumed to have 50% moisture, 47.4% fiber and 2.3% soluble solids with gross calorific value (GCV) of dry ash free bagasse being 19400 kJ/kg while bagasse at 50% moisture content having GCV of 9600 kJ/kg at net calorific value (NCV) of 7600 kJ/kg (Hugot, 1986). Ghosh (Ghosh, 2003) and Barroso et al (Barroso et al., 2003) show that bone dried bagasse presents a GCV of 17632kJ/kg while at 50% moisture it has a net calorific value (NCV) of about 8816 kJ/kg. Manohar (Manohar, 1997) reported that wet mill bagasse has moisture content 50%, fiber pith 47%, sugar 2.5% and mineral 0.5%. The typical composition of bagasse from sugar mill is depicted in table 2-1 and proximate and ultimate analysis is depicted in table 2-2.

Table 2.1: Composition of bagasse of sugar mill (Hugot, 1986; Manohar, 1997)

Composition	**Percentage (%)**
Fibre	43-52 (*Av. 47.7*)
Moisture	46-52 (*Av. 50.0*)
Soluble Solids	2-6 (Av. 2.3)

Table 2.2: Proximate and ultimate analysis of bagasse (Hugot, 1986)

Proximate analysis (% weight)		**Ultimate analysis (% weight)**	
Fixed Carbon	7.0	Carbon	23.7
Volatiles	42.5	Hydrogen	3.0
Moisture	49.0	Oxygen	22.8
Ash	1.5	Moisture	49.0
		Ash	1.5

Other physical properties of bagasse are as follows

- ✓ White and light green appearance
- ✓ Odorless
- ✓ Typical specific weight – 250 Kg/m^3

2.3.2 Comparison of bagasse and other fuels

Comparison of the energy value of bagasse with other fuels such as of natural gas, fuel oil and coal is shown in Table 2.3. Though lower than that of the conventional fuels, its availability at the factory and cheap transport costs makes bagasse the better option in sugar industries especially if moisture content is lowered.

Table 2.3: NCV for common fuels (Vijayaraj, 2009)

Fuel	**NCV (kJ/kg)**
Natural gas	46816
Fuel oil	41800
Coal	29030
Dry molasses	15090
Dry bagasse (Bone dry)	17765
Wet bagasse at 15% moisture	16344
Wood at 15% moisture	15090

2.4 Drying Concepts

Drying is a general concept used to remove moisture or liquid from wet solid by bringing or changing the moisture to gaseous state. In bagasse drying as in most cases of drying ,water is evaporated. Drying process is a simultaneous heat and mass transfer operation widely used in a variety of thermal applications (Hossain & Bala, 2002). In general, the main goal of drying is to decrease the moisture content of solid materials to below certain limit which results in quality enhancement and ease of handling for further processing (Sokhansanj & Jayas, 1995).

In drying, the heat supplied is transferred by convection from the surroundings to the particle surfaces and from there by conduction. Figure 2.2 shows the drying rate curve for a specific product. Initially the graph depicts a constant rate period. The drying rate in the constant rate period is governed by the rates of external heat and mass transfer since a film of free water is available at the evaporating surface. The drying rate in this period is independent of the material being dried.

At the critical moisture content (M_c) the drying rate begins to fall with a further decrease in moisture content. This is because water cannot migrate to the surface at the same rate as in the constant rate drying period because of internal transport limitations. Under these conditions, the drying surface becomes first partially unsaturated and then fully unsaturated until it reaches the equilibrium moisture content.

In many cases of drying however, the dry basis moisture content decreases linearly with time following the start of evaporation until a nonlinear phase due to decrease in moisture content until the equilibrium moisture content is reached where drying stops. The equilibrium moisture content is the limiting moisture to which a given material can be dried under specific conditions of air temperature and humidity. Bagasse moisture content reduction has effect on the amount of steam produced and the resultant saving. This is clearly shown in table 2.4.

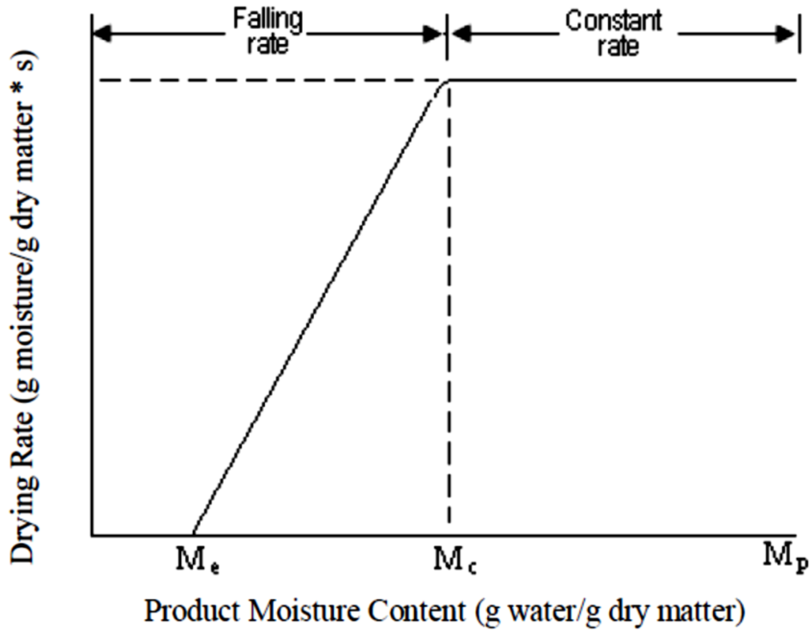

Figure 2.2: Schematic representation of drying rate curve (Syahrul, Hamdullahpur, & Dincer, 2002)

Table 2.4: Technical characteristics of bagasse at various levels of moisture content (Mittal, 2005)

Characteristics	**Moisture content w.b. (%)**		
	30	**40**	**50**
Steam production kJ/kg of green bagasse (50% moisture content)	2.41	2.33	2.2
Percentage saving of green bagasse (%)	9.09	5.03	-
Percentage saving of green bagasse taking boiler efficiency into consideration (%)	10.49	6.04	-

From the table it can be deduced that bagasse drying increases steam production and saving of the amount of bagasse burned. Use of dry bagasse results in reduction of excess air and in turn a saving in loss of sensible heat. Dry bagasse increases the combustion temperature and improves boiler efficiency by reducing the load on the induced draft fans. (Upadhiaya 1991). Previous experiments also confirms that drying also reduces both air pollution and air demand in the furnace (Boulet, 1976) and increases efficiency of the boilers (Edwards, 1981).

Bagasse at 45% is considered excellently milled whereas at 52% moisture, the milling efficiency is poor and with low heating value. The moisture content can be reduced by further de-watering through de-watering mills or by drying the bagasse. The value of bagasse as fuel depends largely on its gross calorific value (GCV), which in turn is affected by its composition especially water content (Das, Ganesh, & Wangikar, 2004) The GCV of bagasse ranges from around 9456 kJ/kg for 50% bagasse moisture to about 14300 kJ/kg at 25% moisture (Vijayaraj, 2009).

2.5 Moisture Content Reduction Methods

Bagasse dryers are classified according to the method of operation and method of heat supply (Toei, Okazaki, & Tamon, 1994). The dryers range from batch types to continuous ones. (Devahastin & Mujumdar, 1999). A continuous dryer is used for high rate of drying while the batch type is suitable for drying at rates below 100kg per day .

Dryers can also be classified on the basis of pressure (vacuum or near atmosphere), temperature of the product during drying, mode of operation, and the method of material handling. Hence a dryer could be stationary, agitated, fluidized, converged and fully under gravity (Syahrul et al., 2002). Other classifications are direct or contact dryers and indirect or non-contact dryers.

The above methods are classified into four main moisture reduction methods (Upadhiaya, 1991):

1. Mechanical method
2. Use of hot imbibition water
3. Chemical methods
4. Other drying methods of bagasse

2.5.1 Mechanical method

After the sugarcane has been harvested and transported to the mill yards, it is loaded into the crushing bays where through conveyors, the cane is led into the heavy duty cutter chamber where the cane is crushed in a process known as shredding. Shredded stems are passed through another crusher where they are crushed further into small particles for maximum leaching of the sugars.

2.5.2 Use of imbibition water (Diffuser)

After the shredder stage, the shredded particles or pieces are fed into the diffuser. In the diffuser hot water is sprayed on the blanket of bagasse entering the diffuser chamber. The hot water or imbibition water is used for leaching and extraction of sugars contained in the bagasse. The process extracts more sugar and reduces the loss in the bagasse. At the same time by using hot imbibition water, the temperature of the bagasse is increased and the wet bagasse travelling from the diffuser to the mills is softer. The extracted juice is taken to the storage tanks from where it is transferred to the process house. The imbibition water used is at about 70°C to 80°C using the hot condensates.

2.5.3 Chemical method

The sugar and water are held in bagasse primarily by surface forces, the reduction in the surface tension on adding suitable chemicals to the bagasse matrix to reduce the sugar loss and moisture content in the bagasse. For example the additions of a high polymer of ethylene oxide and polyoxy-prophlene called extrapol reported a reduction of the pol percentage of bagasse from about 4.5% to 3.9% resulting in recovering 5% extra sugar (Bacon & Otrahaler, 1954). Another additive called "Sushira" (Ramaiah, Srivastava, & Tewari, 1979), reported 0.6 to 0.8% reduction in pol with a decrease in the moisture content of the bagasse by about 3%. The chemical methods have a basic limitations of maximum moisture reduction of only 3% to 4%.

2.5.4 Other Drying methods

The wet bagasse from the diffuser with a lot of slippage, is transported through slat conveyors to the two sets of heavy duty mills In the first mill, the wet bagasse is squeezed at high pressure and the extracted juice is further collected into the storage tank. At this point the bagasse still has a considerable amount of water, and is passed through mill two for further extraction. The juice is also collected in the storage tank and pumped to the major storage tank in the diffuser.

At the end of mill two , bagasse has moisture content of about 45 to 50% and has a heating value of up to about 4.22MJ or 1173.16Wh. This value however can be increased if the bagasse is dried to below 45% moisture content (Upadhiaya 1991).

2.6 Direct and Indirect Dryers

2.6.1 Direct or contact dryers

These are also called adiabatic or contact dryers and transfer heat by direct contact of the product with the hot gases. The gas transfers sensible heat to provide the heat for vaporization of the moisture .This method has a high rate of heat transfer due to direct contact between the flue gas and the raw material, it has short residence time and provides uniform drying .

Direct dryers generally operate in concurrent mode to avoid possibility of ignition. However since bagasse contains very high moisture and the waste gases contain significantly low quantities (less than 8% by weight) of oxygen, a center current dryer can be advantageously adopted to save on cost and space for dryer installation. Nevertheless, contact type dryers will have suitable provision for fire-fighting because of possibilities of leakage air ingress.

Its main component is a steel shell set up on rollers by means of bandages (hoops) located in the shell. The cylindrical chamber is usually inclined with a slope to the horizontal so that solid slowly progress through the dryer under gravity. Additional requirements for direct (contact type) dryers, is that it becomes necessary to separate the waste gases (with dried out moisture) from the fine dust of bagasse that would be carried along.

2.6.1.1 Bagasse drying with exit steam

Exit steam is the high temperature steam ejected from the boiler or sugar factory process house after driving the steam turbine.

The steam at high temperature comes in contact with the moisture of the bagasse, and heat exchange occurs between the steam and the moisture.

As a result, the temperature of the supplied steam will drop while that of the moisture will increase .The total steam in the system is subsequently removed by venting or by the help of external pumps.This method is preferred to external heating because external heating may require more heat due to heat loss as a result of radiation and convection as shown in the figure 2.3 (Yarnal & Puranik, 2010).

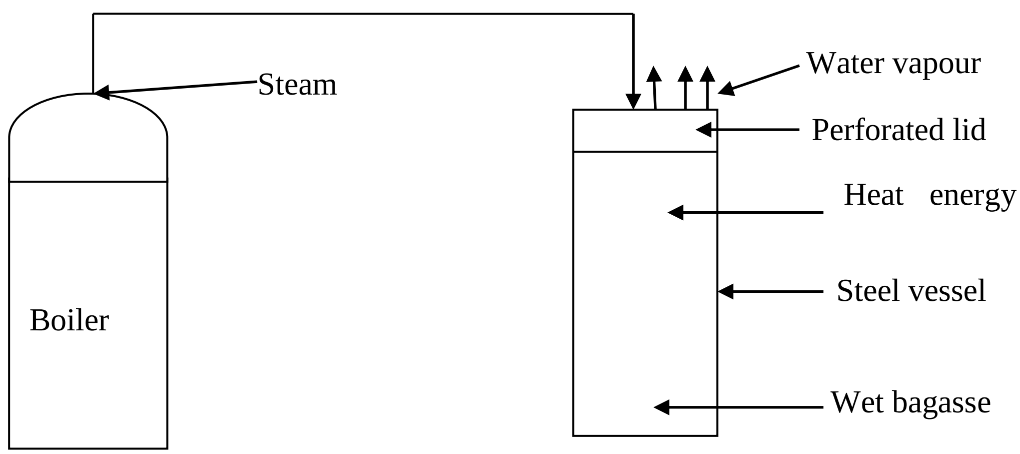

Figure 2.3: Bagasse drying with exit steam

2.6.1.2 Bagasse drying with hot flue gases

In drying with hot flue gases, the bagasse dryer is installed in-line with the boiler stack gases. Since the boiler stack gases contain enormous amount of energy with the temperatures usually around 250 °C. at exit, by this method some energy in the waste gases is recovered and used. The typical methods of drying bagasse using steam and flue gases include:.

- ✓ The parallel arrangement of bagasse drying method
- ✓ The sequential arrangement of bagasse drying method
- ✓ The combined flue gas/steam drying.

A. Parallel flow arrangement of pre-heating and drying

In the parallel arrangement, Figure 2.4, the combustion gases that leave the boiler are tapped into the pre-heater and drier simultaneously (in parallel) at the same temperature. The wet bagasse in the drier is then dried by heated air which removes the moisture from it through evaporation. (Sosa-Arnao & Nebra, 2009).

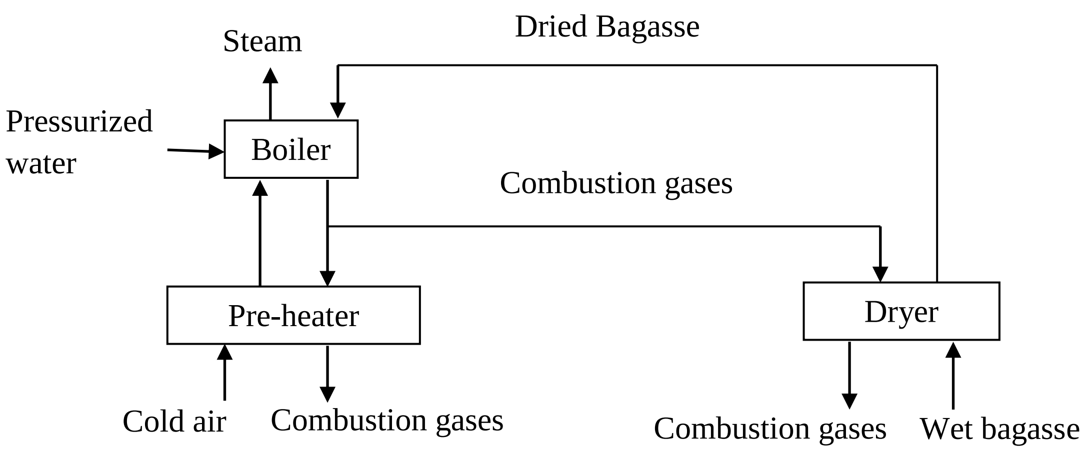

Figure 2.4: Parallel flow arrangement of pre-heating and drying (Yarnal & Puranik, 2010)

B. Sequential flow arrangement of preheating and drying

In this dryer type unlike the parallel arrangement, the combustion gases leaving the pre-heater enter the drier directly hence the amount of moisture removed from the wet bagasse is less compared to parallel flow arrangement. The heat content of the combustion gases that enter the sequential arrangement are less than that of parallel arrangement. In both cases however, there is no balance between the dry bagasse used in the boiler and dry bagasse generated in the drier. (Sosa-Arnao & Nebra, 2009). Figure 2-5 shows the typical arrangement of the sequential flow arrangement.

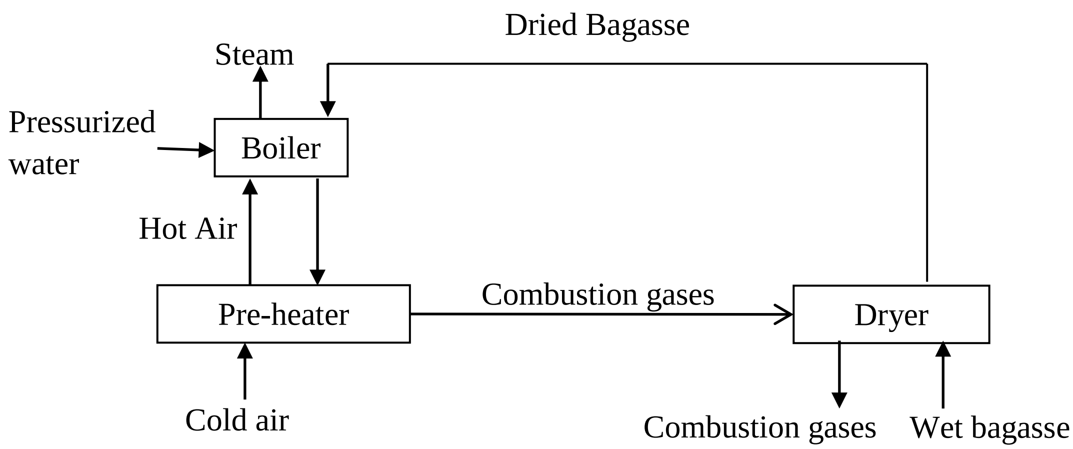

Figure 2.5: Sequential flow arrangement of preheating and drying (Yarnal & Puranik, 2010)

C. Bagasse drying with combined flue gas/steam heating

Figure 2.6 is a schematic for this drying method. The method uses combination of combustion gases and steam from the boiler to heat the bagasse in the dryer. The steam is tapped from the boiler and fed to the drier and similarly the steam, after picking up moisture from the wet bagasse in the drier, is again fed to the boiler hence the enthalpy of the steam along with the vapor moisture is not lost.

The method compensates the excess heat content corresponding to the heat that is present in the stack gases with the steam produced in the boiler , thereby creating balance between the dry bagasse used in the boiler and generated in the dryer. (Yarnal & Puranik, 2010). This method is the ideal arrangement for MSC.

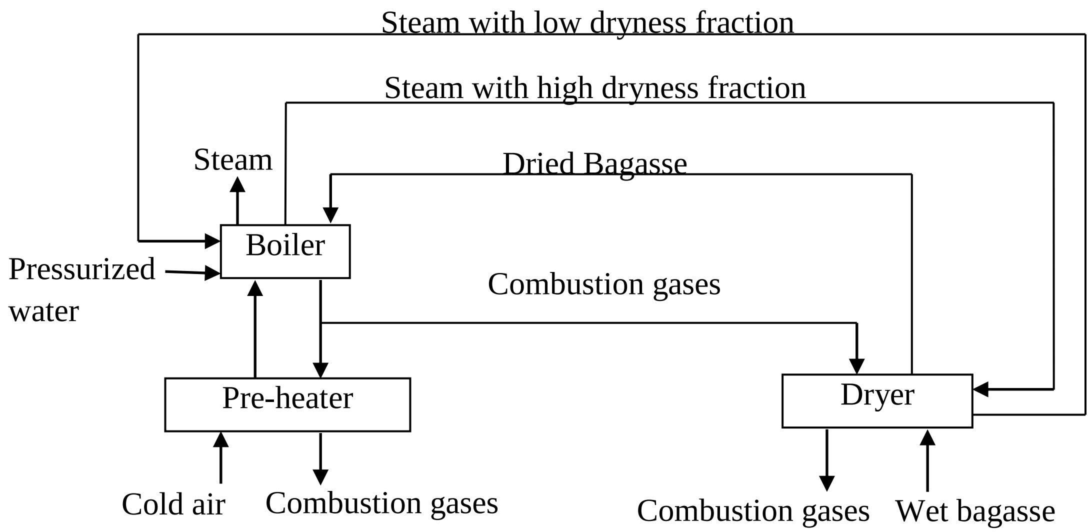

Figure 2.6: Bagasse drying with combined flue gas/steam heating (Yarnal & Puranik, 2010)

D. Comparison of Parallel and Sequential Arrangements of preheating and drying

The parallel and sequential arrangements are both simple and easy to install. Also in both arrangements there is no balance between the dry bagasse used in the boiler and the dry bagasse generated in the drier. However, unlike sequential arrangement, parallel arrangement has a lot of thermal energy left in the gases leaving the preheater.

To avoid the possibility of the combustion gases getting mixed up with the steam, the steam and flue gas lines are operated with the EITHER/OR mode so that at any point of time there will be no mixing of the steam and combustion of gases. For MSC, the combined arrangement of flue gas and steam heating would be better to tap the excess steam from the boiler and flue gases.

2.6.2 Indirect or non-contact dryers

These are also called non-adiabatic dryers or units, where the heat transfer medium is separated from the product to be dried by a metal wall due to high temperatures which can cause ignition when they come into direct contact with the medium being dried. In the case of bagasse drying, the heat transfer is only through conduction and forced convection as no radiative heat transfer takes place at those lower temperature of operation. This method can reduce moisture content from around 50% to 45%.

A typical indirect dryer for bagasse application can be a bin dryer which is kept vertical with large diameter (100mm) pipes passing along the vertical axis at a pitch of 450mm to 600mm with bin circumference also lined with vertical steam pipes. The pipes are fed at the top with low pressure steam or flue gas with radial outlets from a common feed header, reaching to individual pipes. The pipes are again connected together at the bottom end and the condensate or exhaust is removed from the system.

The bagasse is charged to the dryer at the top from belt conveyors. The bagasse descends vertically down to the bottom where it is extracted by a gas extractor. During its travel down the container bin, the bagasse gets dried by physical contact with the steam pipes and the liberated water vapor travels up and out of the container bin.

2.7 Solar drying of bagasse

In solar drying of bagasse, natural or forced air convection is used The air heated by solar to low temperature ranges of 28-52°C makes direct contact with the sample .The solar dryer is constructed from available and cheap local materials . (Abdel-Rehim & Nagib, 2007).

Solar drying of bagasse uses two main methods namely open sun drying and sun drying using dryers.

2.7.1 Open Sun Drying (OSD)

This method exposes the bagasse to direct insolation supplemented by natural convections..

The drying process starts when the absorbed energy is converted into thermal energy and the temperature of the material being dried rises. The material then begins emitting long wavelength radiations to the ambient air through moist air. The air moving over the material being dried also causes drying through convective heat loss and results in evaporative heat losses. At the start of the drying process, there is rapid moisture removal from the material surface. When the equilibrium is reached, no further drying takes place. Open air drying is affected by the amount, size and type of the product to be dried (Whitfield, 2000).

The advantages of this method of drying include: low capital investment, low operating costs and does not require a high level of technical expertise. The major disadvantage of using OSD is that it does not meet international standards of quality drying. Other disadvantages are interference by air movements, rodents, birds, insects and unexpected rains.

2.7.2 Solar Driers

Solar drying systems are classified according to their heating modes. One is called active solar energy and the other is passive drying system. (Ekechukwu & Norton, 1999). The first one is called active solar energy drying systems which are normally referred to as hybrid solar dryers and the second classification is passive solar energy drying systems which are conventionally referred to as natural circulation solar drying energy systems.

Both the active and passive drying drying systems are further classified by the design arrangements of components as discussed in 2.8.2.1 and 2.8.2.2.

2.7.2.1 Direct type Solar Drying (DSD)

Direct solar drying, also known as natural convection cabinet drying, has the material directly exposed to the sun and utilizes the natural movement of the heated air to dry the products. Part of the radiation incident on the glass cover is reflected back to the atmosphere while the rest is transmitted into the cabin dryer and part of the transmitted radiation is reflected back from the surface of the product.

The temperature inside the drying chamber gradually increases and the glass cover serves to reduce losses via direct convection to the atmosphere which enhances the rise of the chamber temperature (Sharma, Chen, & Lan, 2009).

The dryer consists of a shallow chamber covered by a transparent material, usually glass or plastic. The chamber is insulated box with air-holes in it to allow air to enter or exit the box. In this dryer, the product is placed on a perforated tray that allows air to pass through it and the material being dried

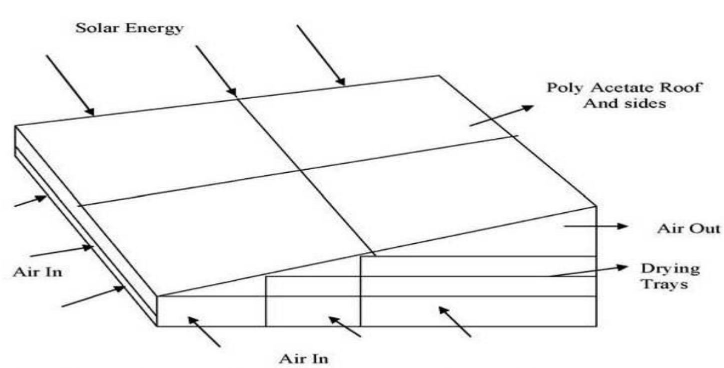

Figure 2. 7: Direct solar dryer

The dryer design accelerates the drying and reduces the time to 20% that of OSD.

2.7.2.2 Indirect type Solar Dryers (ISD)

In an ISD as shown in the figure 2.8 the products is not directly exposed to the incident radiation .Unlike in the DSDs. This minimizes discoloration and cracking on the surface of the product and is prefered for products like tomatoes which are discolored by direct radiation.

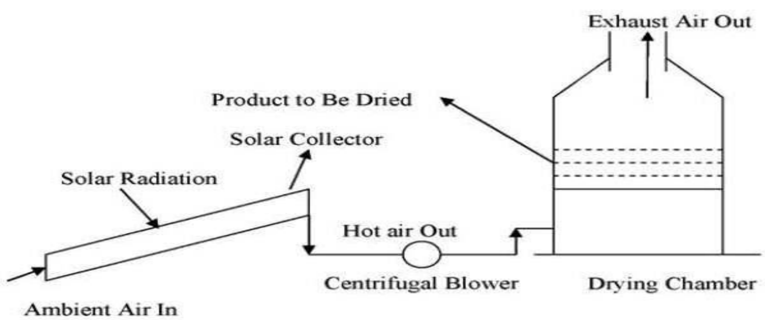

Figure 2. 8: Indirect Solar dryer

A separate solar air heater is used for heating the air which is then directed to an opaque drying chamber which houses the product.

This type of dryer gives a better control over drying and the product obtained is of good quality. Other types of solar dryers developed for various purposes include natural convection cabinet type, green house type and solar tunnel types.

2.7.3 Merits and Demerits of Solar Drying

As with all the methods utilized in drying the bagasse, solar drying has its advantages and disadvantages. The advantages include better quality of products, reduction in losses and products that are protected from exposure to flies, rain and dust.

The disadvantages of solar drying includes inconsistent solar radiation and longer drying time. (Toshniwal & Karale, 2013).

2.8 Mumias Sugar Company

The plant of study is Mumias Sugar Company (MSC) located in Mumias Town midway along Kakamega - Bungoma Road in Kakamega County Western Kenya at a longitude $34^{0}30'$ East and latitude 0°21' North at altitude of 1314 m above sea level. The factory is the leading sugar factory in the country and the entire East Africa. The company was started in July 1st 1971 with the government holding majority shares of 71% while the minority shares were held by the Commonwealth Development Corporation (17%), Kenya Commercial Finance Company (5%), Bookes McCanvel (4%) and the East African Development Bank (3%).

Currently the company has a crushing capacity of 8000 tons of cane per day and generates 36MW from cogeneration out of which it exports 26MW to the national grid and consumes 10MW for the running of its utilities.

The processes in the factory begins with cane cutting and delivery to the factory as the raw material. The cane is loaded into the crushers onward to the diffuser and mills for juice extraction. The produced bagasse which is the main focus of this project is then transported to the boilers as the main source of fuel.

2.8.1 Review of bagasse drying methods in MSC

MSC as other sugar factories globally relies on bagasse as its fuel for its own use and for the production of process steam and electricity from cogeneration system for the supply to the grid. The factory though the largest in East Africa at a crushing capacity of 8400 tons of cane per day

(TCD) which translates to about 3200 tons of bagasse has no special way of drying its bagasse. From the mills the bagasse is sent to the boilers for use as fuel and any excess or unused bagasse is taken to the bagasse store where it dries by natural air.

When the store is full, the excess bagasse is put in the open air in front of the store where it dries from the direct solar energy. In this case it is also exposed to rain and may not dry progressively.

Though the factory emission of flue gases from the boilers is at temperature range of 120 – 180°c, no attempt has been made to use the gases as a way of drying the bagasse. Neither has exit steam from the process house been used for drying of bagasse.

2.8.2 Boilers at MSC and their capacity.

In its effort to be independent of power from national grid, the company continues to invest and adopt cheaper and efficient ways of production. As such the company has various boilers and turbo alternators (TAs) which are usually run as the need dictates. The company has the following installed boilers and turbo alternators (TAs)

a) Boilers

  i. Cogeneration plant: Rated 170 Tonnes Per Hour (TPH) at 87 Bar

  ii. Sugar Plant:

    - Boiler 3B: 120 TPH rated at 22 Bar and 380 – 385°C steam temperature.
    - Boiler 1B & 2B: 55 TPH rated at 22 Bar and 380°C steam temperature.
    - Boiler 1A & 2A: 22.68 TPH rated at 22 Bar and 380°c ± 15°C steam temperature.

  ii. Ethanol plant: 22 TPH at 45 Bar and 7.5 Tonnes for Vinnase

b) Turbo alternators

i. Cogeneration plant – 34.2MW

If all the equipment were operational, the requirement for bagasse would be as follows:

- ✓ Cogen: $70 TB/H\ x\ 24 = 1680\ T\ \ of\ Bagasse/day$
- ✓ Boiler 3B: $60TB/H\ x\ 24 = 1440\ T\ of\ Bagasse$
- ✓ Boiler 1B & 2B: $27.5TB/H\ x\ 24\ x\ 2 = 540\ x\ 2 = 1080\ T\ of\ bagasse$
- ✓ Boiler 1A & 2A: $11.34TB/H\ x\ 24\ x\ 2 = 272.16T\ of\ bagasse$
- ✓ Ethanol plant: $5TB/H\ x\ 24 = 120\ T\ of\ Bagasse$
- ✓ Total design specification: $4592.16\ T\ of\ bagasse$

The amount of bagasse produced is therefore given as

$$Fibre\ \%\ x\ 2\ x\ Tonnes\ of\ Cane\ Per\ Hour = Bagasse/hour$$

% Fibre x 2 x Tones of Cane per Hour =Bagasse/ Hour.

17.5% x 2 x 350 = 122.5 Tones / Hour x 24.

=2940 Tones / Day.

Actual bagasse production =2940/ 4592.16 =.6402=64.02%

The 2940 Tones per day is less compared to the rating amount of 4592.16 Tones per day leaving a deficit of 1652.16 Tones which necessitates re- arrangement of boilers and Turbo alternators operations for maximum power output as follows:

- $cogeneration\ \ and\ TA1\ or\ TA2\ =\ 34MW\ +\ 2.5\text{MW}\ =\ 36.5\text{MW}$

  or,

- $cogenation\ with\ TA2\ \&\ TA6\ =\ 34\text{MW}\ +\ 2.5\text{MW}\ +\ 1.25\text{MW}\ =\ 37\text{MW}$
- $TA3\ \&\ TA6\ =\ 34MW\ +\ 2.5\text{MW}\ +\ 1.25\text{MW}\ =\ 37.75\text{MW}$
- $TA2\ \&\ TA3\ =\ 34\text{MW}\ +\ 2.5\text{MW}\ +2.5\text{MW}\ =\ 39\text{MW}$

An average power of about 37MW is therefore generated out of which the company uses about 11MW and the rest sold to the national grid. The above arrangement also dictates the bagasse utilization for the running cogeneration boiler and boiler 3B.

CHAPTER THREE: METHODOLOGY.

3.0 Introduction.

The first stage of the project was the familiarization of the company's safety regulations and requirements and operations in sugar production such as cleaning of canes, milling of canes, extraction of juice, concentration of juice, removal of impurities by addition of calcium phosphate lime and double carbonization of double sulphunation, concentration of juice by evaporation, crystallization, separation of sugar through centrifuge, that is, centrifugation of crystals and final packaging and handling of sugar. The other operations also include the methanol plant and the water bottling plant. There was also the familiarization of the different methods of drying bagasse at the company and the general energy use.

The entire study period lasted thirteen months from January 2012 to January 2013. The period of study was designed to cover the different seasons ,namely, the dry, the short and long rainy seasons.

3.1 Design, fabrication of the dryers

3.1.1 Steel dryer

The steel dryer was designed and fabricated using 3mm mild steel sheets and 50 x 50 x6 mm angle iron.

The drier dimensions are as shown in figure 3.1.The 1600mm x 600mm x320mm tray had 10mm markings to facilitate uniform spreading of bagasee. Two openings of 50 mm x260 mm were provided on each of the 1600 mm sides for escape of moisture.

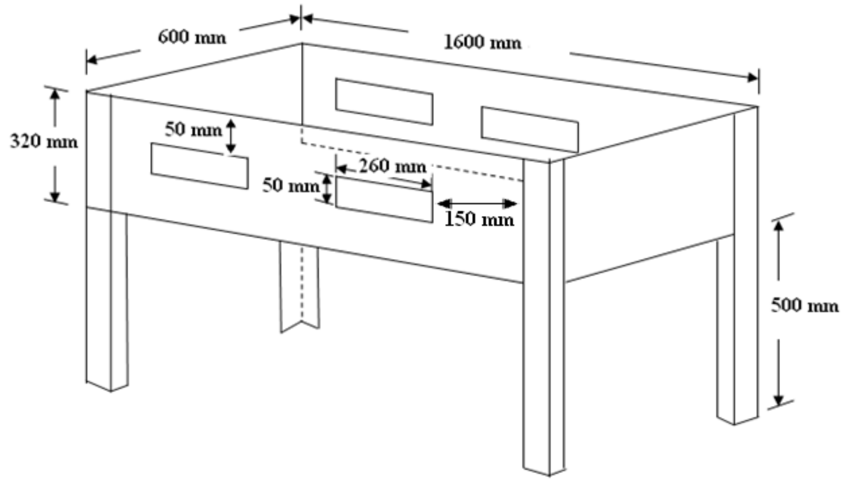

Figure 3.1: Steel Dryer

3.1.1.1 Glass dryers

This drier was different from the steel drier in that the sides of the tray were made of glass. It had one opening of size 240 x 100 mm on each of the long sides for escape of moisture as shown in figure 3.2

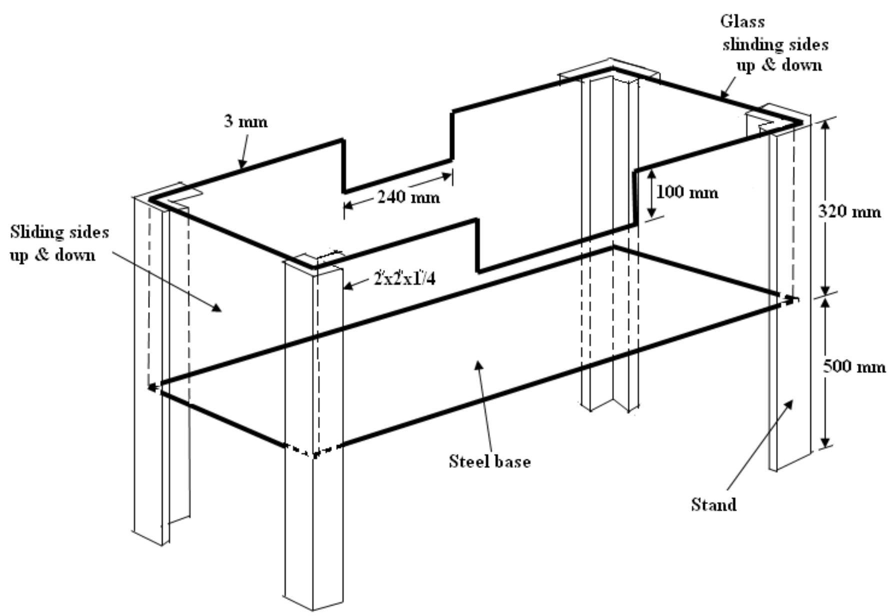

Figure 3.2: Glass dryer

3.2 Experimental tests.

The bagasse was scooped from the conveyor belt immediately after mill 2 loaded in buckets of known weights. Actual weights of bagasse in a bucket was determined as was the total for each dryer. (Salter Brecknell SNCS – 08A7957 ESA 3000). The experimental procedures were as shown in **Appendix 1.**

3.2.1 Temperature and relative humidity measurement procedure

Determination of temperatures and the relative humidity of the air above the bagasse was done by spreading the bagasse in the drier to a known depth guided by the calibrated lines on the dryer sides. Other depths to which bagasse was spread were 30cm, 40cm, 50cm, 60cm, 70cm, 80cm, 90cm, 100cm and 110cm.After this, the digital thermo hygrometer was placed in its secure cage on top of the bagasse. Fig. 3.3 and Fig. 3.4

The dryer was covered with the glass lid in the case of the closed experiment. After an interval of one hour, readings of temperature and relative humidity were taken at one hour interval from 0900hrs to 1700hrs.

Figure 3.3: Covered steel dryer

Figure 3.4: Open Glass Dryer with digital thermal hygrometer

3.2.2 Moisture content test

Determination of the moisture content is the most critical component in bagasse drying experiment. The test was done in three stages. In the first stage, it was done every day at the beginning of the experiment. In the second stage it was performed at intervals of one or two hours and in the final stage it was done at the end of the experimental day.

The test procedure involved weighing 100g bagasse sample in a weighing balance Fig 3.5 which was then set in the oven of set temperature at 106^0C for four hours Fig 3.6. The dried sample was then removed and reweighed to determine reduction in moisture content. The readings were then recorded as shown in **Appendix 2.**

Figure 3.5: 100g bagasse sample on a weighing balance

Figure 3.6: Bagasse sample set in the oven

3.2.3 Test procedure for continuous drying

In the continuous drying experiment, the procedure was the same as steps in the moisture content test with the exception that at the end of the experimental day the test sample is not weighed and discarded. The bagasse would left in the dryer while moisture escape holes on the sides of the dryer would be sealed using polythene to avoid moisture from outside getting into the sample at night. In the morning the sealings would be removed and the moisture content determined after every two hours interval.

Table 3-1 shows the results for the week during the period 22nd to 27th of October 2012.

Table 3. 1: Bagasse utilization for October 2012

Date	**Bagasse produced (T)**	**Bagasse consumed by cogen (T)**	**Bagasse consumed by boiler 3B (T)**	**Total consumed**	**Baggase returned to store (T)**	**Bagasse used from the start (T)**
22/10/2012	2962.83	1232	1440	2672	290.83	-
23/10/2012	2431.37	998.0	1440	2438	-	6.63
24/10/2012	1104.92	558	1440	1998	-	893.08
25/10/2012	2921.15	-	1440			
26/10/2012	2838.76	1280	1440	2720	118.76	-
27/10/2012	2254.61	1232	1440	2672	-	417.30

CHAPTER FOUR: RESULTS AND DISCUSSIONS.

4.0 Comparison of performance of dryers.

4.1.1 Perspex covered glass and steel dryers.

The experimental results of the glass dryer covered with Perspex glass are tabulated in the Table 4.1 with the graphs for the results in Figure 4.1, and that for the steel dryer are tabulated in the table 4.2 with the graphical representation in Figure 4.2 . In both cases Perspex glass was used as the only covering material. The sample moisture content and weights were determined at the start and end of the experiments only.

Table 4.1: Glass dryer covered with perspex glass 2nd July, 2012.

Time (hrs)	Temperature inside the Dryer (°C)	Solar Insolation (W/m^2)	Relative Humidity (%)	Sample Moisture content .	Sample Weight (kg)
900	25.2	113.25	55	50.1	9.396
1000	37.2	134.93	53	-	-
1100	41.2	115.51	37	-	-
1200	53.2	85.71	27	-	-
1300	50.3	80.5	15	-	-
1400	57.1	81.4	18	-	-
1500	50.9	78	15	-	-
1600	47.4	76	10	-	-
1700	45.3	70	11	41.8	7.938

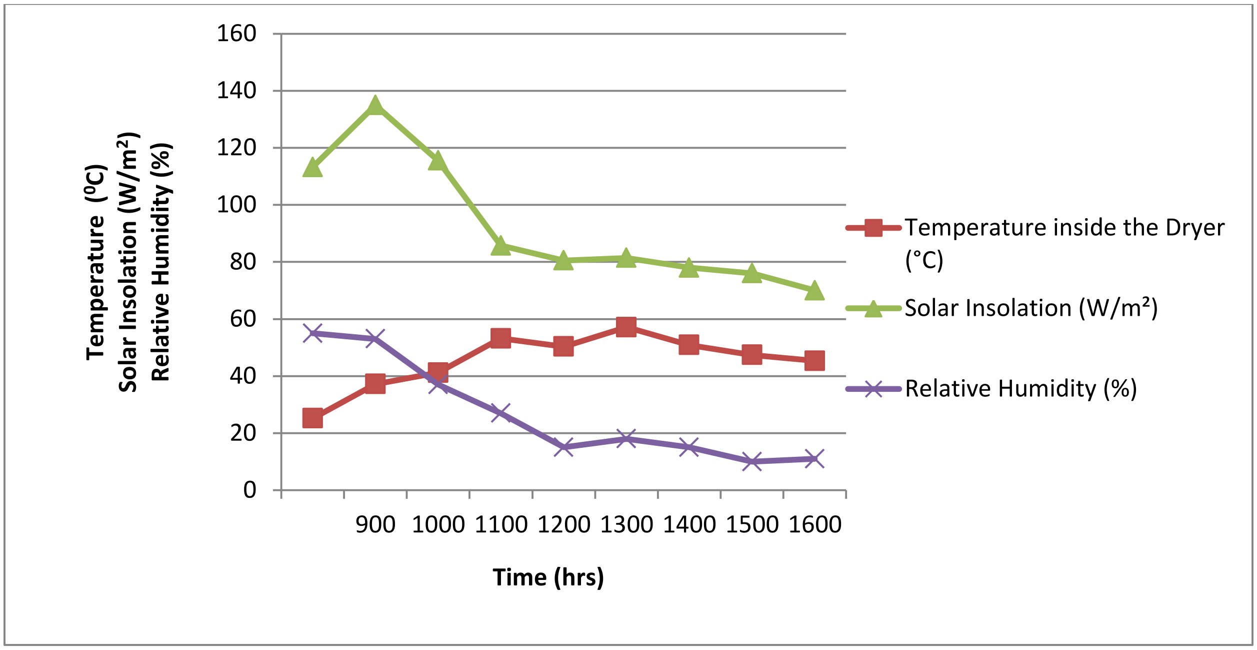

Figure 4.1: Temperature, solar insolation & relative humidity versus time for glass dryer covered with perspex glass .

Table 4.2: Steel dryer covered with perspex glass 2nd July, 2012.

Time (hrs)	Temperature inside the Dryer (°C)	Solar Insolation (W/m^2)	Relative Humidity (%)	Sample Moisture content for Baggase (%)	Sample Weight (kg)
930	30	90.4	56	50.1	7.37
1030	39.6	93.49	55	-	-
1130	49.9	133.19	40	-	-
1230	57	115.63	15	-	-
1330	60	79.13	20	-	-
1430	64.1	45.28	11	-	-
1530	49.8	41.3	10	-	-
1630	45.8	38	16		
1730	36.8	34	24	42.75	6.032

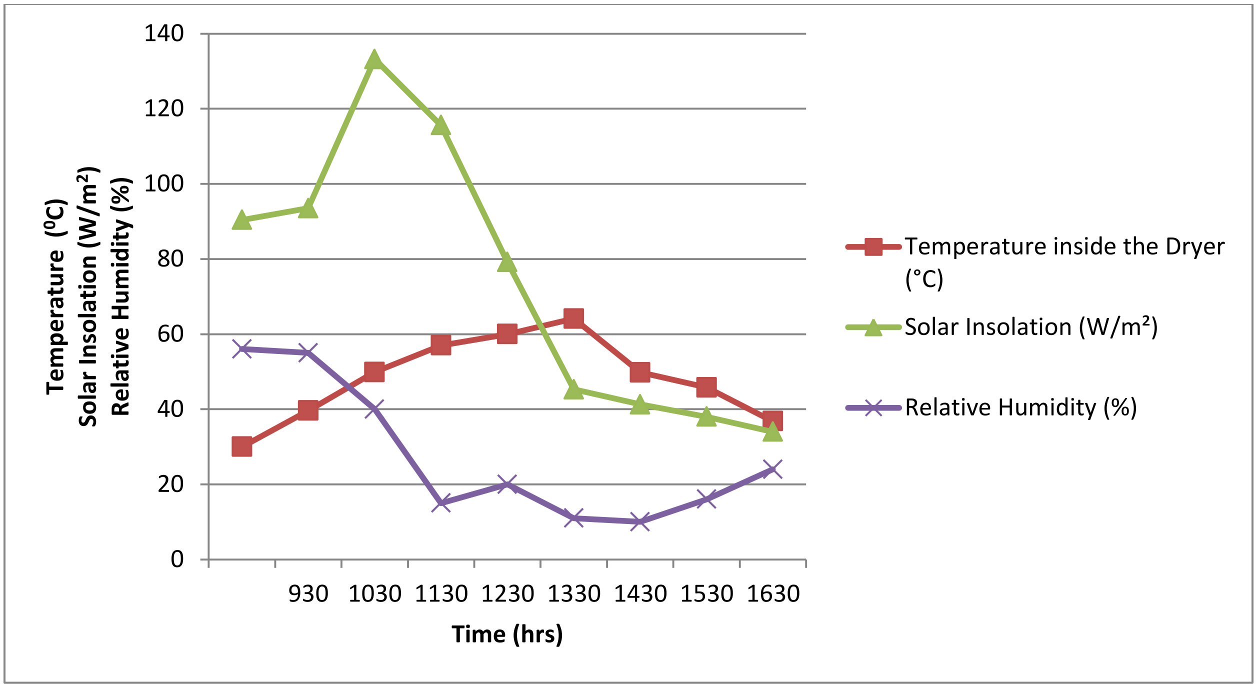

Figure 4.2: Temperature, solar insolation & relative humidity versus time for covered steel dryer.

The maximum temperature attained inside the steel dryer covered with glass was 64.1°C at 1430hrs. This was higher than the glass dryer covered by glass which was 57.1°C at 1400hrs.

The Relative Humidity (RH) in both the dryers displayed similar profile of change while the moisture content reduction was higher in the glass dryer at 8.3% compared to the steel dryer covered with perspex glass at 7.35% after eight (8) hours of drying.

4.1.2 Open air drying in Steel and Glass dryers.

Experimental results for glass and steel dryers during open air drying are tabulated in the Tables 4.3.and 4.4 respectively. The results are presented graphically in figures.4.3 and 4.4 respectively showing effects of Temperature, Solar insolation and Relative humidity on the sample moisture content (%) of bagasse and weight reduction (Kg). The sample moisture content was determined after every two hours while the overall weight reduction was determined after seven hours.

Table 4.3: Open Glass dryer (11th January, 2013).

Time (hrs)	Temperature inside the Dryer (°C)	Solar Insolation (W/m^2)	Relative Humidity (%)	Sample Moisture content (%)	Sample Weight (kg)
910	27.3	120.8	63	40.2	9.732
1010	35.6	153.77	47	-	-
1110	51.8	120.93	11	36.15	-
1210	54.3	97.06	15	-	-
1310	56.7	47.93	14	28.15	-
1410	44.9	10.98	13	-	-
1510	52.3	9.89	10	27.3	-
1610	49.1	7.55	9	-	8.642

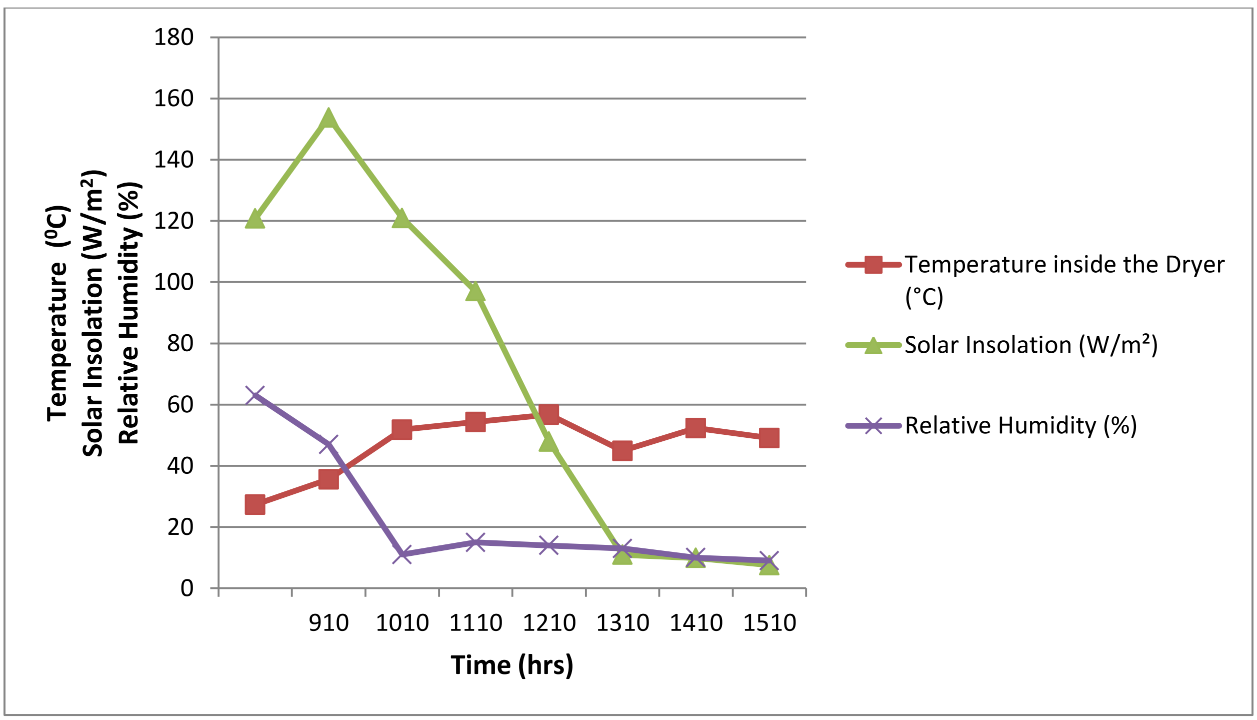

Figure 4.3: Temperature, Solar insolation & relative humidity versus time for open glass dryer.

Table 4.4: Open Steel dryer 11th (January, 2013).

Time (hrs)	Temperature inside the Dryer (°C)	Solar Insolation (W/m^2)	Relative Humidity (%)	Sample Moisture content.(%)	Sample Weight (kg)
900	25.6	122	47	37.95	8.428
1000	34.6	156.34	53	-	-
1100	52.7	154.23	15	35.25	-
1200	53.4	144.62	12	-	-
1300	53	91.75	11	35	-
1400	51.1	33.11	12	-	-
1500	52	8.6	13	24.9	7.483

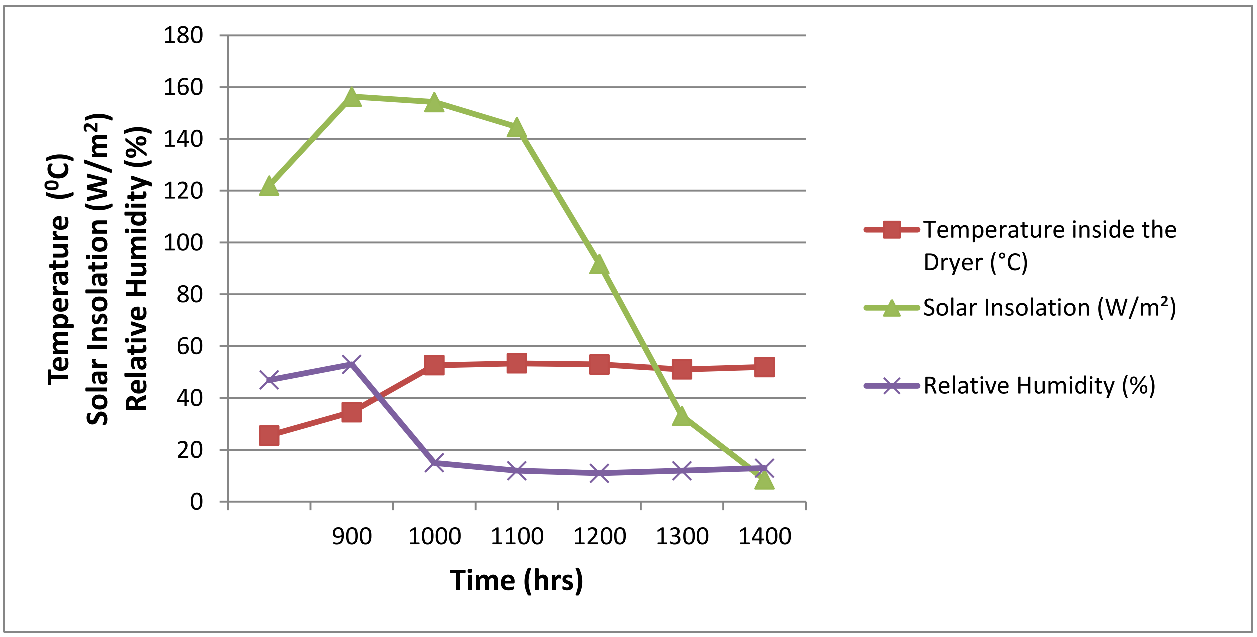

Figure 4.4: Temperature, solar insolation & relative humidity versus time for open steel dryer.

4.1.3 Comparison Summary between Glass and Steel dryers.

In comparisson between open and closed dryes , the tabulated results are shown in Table 4.5. and graphically in Fig.4.5.

Table 4.5. Comparison between dryer types and the Effect of Covering

Date	Dryer Type Comparison	Initial Moisture Content %	Final Moisture Content %	Moisture Reduction %	Drying Time (hrs)
2/7/2012	Glass Covered	50.1	41.8	8.3	8
	Steel Covered	50.1	42.75	7.35	9
11/1/2013	Glass Open	40.2	27.3	12.9	6
	Steel Open	37.95	24.9	12.05	6

The overall moisture reduction was higher in the open dryers at a maximum of 12.90% for glass and a maximum of 12.05% for steel dryers respectively compared to 8.30% for covered glass dryer and 7.35% for covered steel dryer. This could be attributed to a bigger area of exposure to sunlight and wind which speeded up the rate of evaporation compared to covered dryers where the dryer cover limits the free movement of the wind.

Glass dryers provided a higher moisture percentage reduction in open and closed dryers compared to steel dryers over the same number of drying hours. The graphs in figure 4.5 are indications that reductions were dependent on the dryer state.

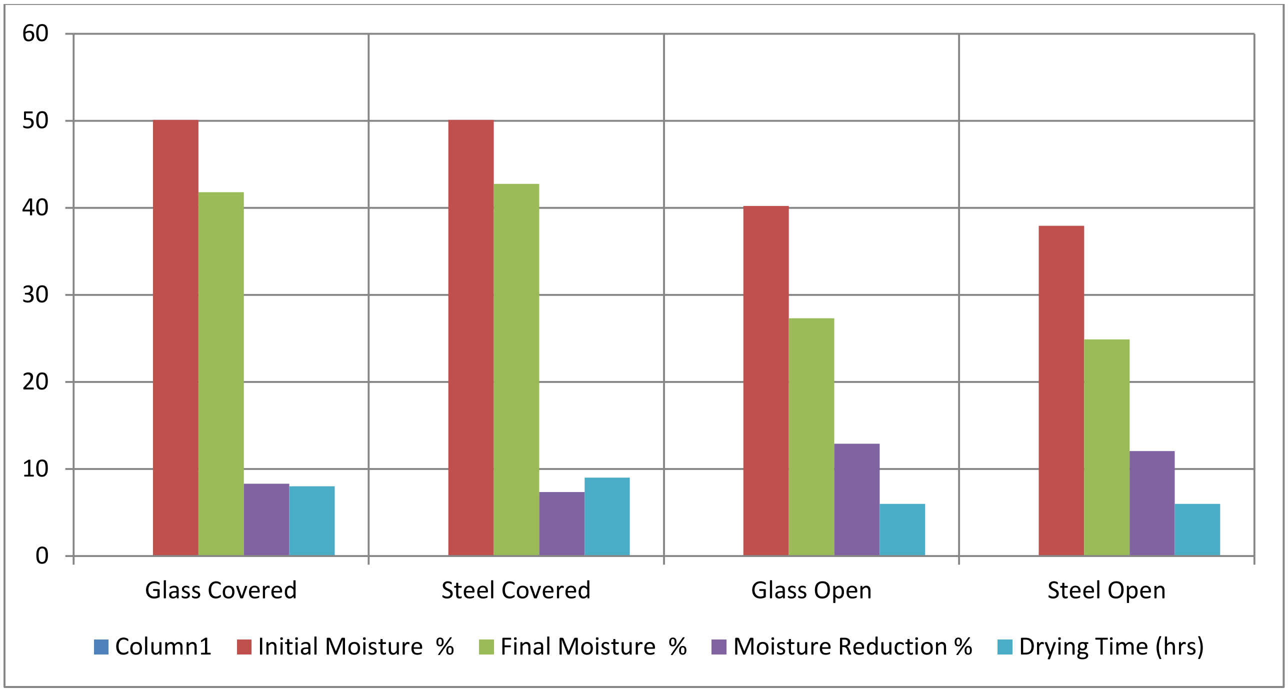

Figure 4.5. Comparison between open and closed dryers

4.2 Continuous drying for 5 days (40hrs).

Continuous drying of bagasse was carried out for 8 hours daily for consecutive 5 days. The change in moisture content during the period is given in Table 4.6 and Figure 4.6.

Table 4.6. Moisture content Reduction in 5 consecutive days of drying.

Day & Time	Moisture Content in Closed Steel Dryer (%)	Moisture Content In Closed Glass Dryer (%)
DAY 1 0910hrs	48.10	48.10
1110hrs	42.90	44.80
1310hrs	37.50	32.50
1510hrs	34.60	29.00
1710hrs	29.00	28.00
DAY2 0815hrs	39.50	35.30
1015hrs	38.85	32.87
1215hrs	29.80	34.94
1415hrs	27.70	31.80
1615hrs	19.20	30.95
DAY3 0820hrs	36.85	28.55
1020hrs	27.60	19.45
1220hrs	23.40	24.90
1420hrs	20.40	12.70
1620hrs	9.85	16.10
DAY4 1140hrs	20.25	20.20
1340hrs	13.65	10.45
1600hrs	5.40	5.45
DAY5 0900hrs	11.65	10.75

In continuous drying of bagasse for 5 consecutive days Figure. 4.6, it was observed that bagasse moisture content was higher every morning, points O, 1, 2,3,4 and 5 compared to the previous day at the close of the experiment.Points O, A, B,C,D and E.This can be attributed to envriomental conditions of high Relative humidity and low temperatures at night which leads to condensation of gases in the dryer.

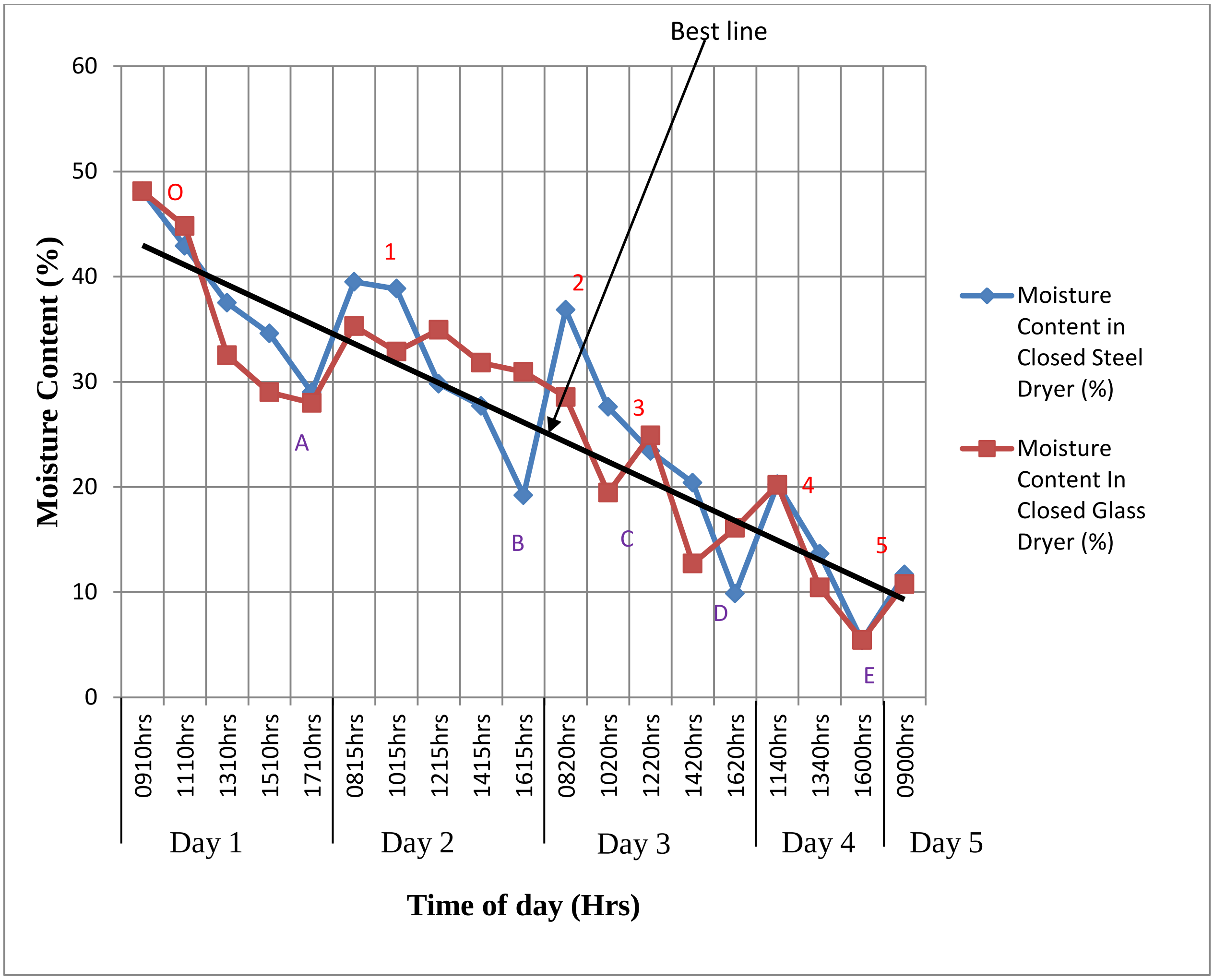

Figure 4.6: Graph of percentage moisture reduction verses drying.

4.3 Moisture Content reduction, Gross Calorific Value (GCV) and Net Calorific Value (NCV) Outplay over time

4.3.1 Bagasse Calorific Value and Boiler Efficiency

Boiler efficiency for bagasse fired boilers depend on many parameters like temperature, heat loss of flue gases, pressure of the boiler system, losses from the furnace and losses due to incomplete combustion and the Calorific Value of the bagasse (Anjuin Munir, 2004).

The Calorific Value of bagasse in turn depends upon its moisture content and sucrose content. In experimental working conditions it has been shown that the Calorific Value is calculated by the formula;-

Gross Calorific Value (GCV) = 8280(1-μ) – 2160S (in kJ/kg) x 2326 (Hugot 1986)- [4.1]

Where;- μ is the Moisture Content of the bagasse

S is the Sucrose in the bagasse taken as 2.3%

Net Calorific Value (NCV) = 7600 – 8730W – 2160S x 2326 in kJ/kg). [4.2]

4.3.2 Sample Calculation of GCV and NCV

Moisture content (μ) of 50% and the sucrose content in bagasse (S) of 2.3%, the GCV and NCV values are calculated as follows for:

GCV = 8280 (1 – μ) – 2160S = 8280 (1 – 0.50) – 2160 x 0.023 x2326(kJ/kg)

= 9514 kJ/kg.

And

NCV = 7650 – 8730 μ – 2160S

= 7650 – 8730 x 0.5 – 2160 x 0.023 x 2326

=7525 kJ/kg.

4.3.3 GCV and NCV for Glass Dryer and Steel Dryer

The measured values of moisture content of Table 4.6 with an assumed content of sucrose of 2.3% was used in equation 4.1 to compute the GCV and NCV as shown in Table 4.7 and Table 4.8 .

Table 4.7: Moisture Content and computed GCV and NCV for Closed Steel Glass

Day & Time	Moisture Content in Closed Steel Dryer (%)	GCV (MJ/Kg) CV (Gross)	NCV (MJ/Kg) CV (Net)
DAY1 0910hrs	48.10	9.879	7.89
1110hrs	42.90	10.861	8.91
1310hrs	37.50	11.921	10.06
1510hrs	34.60	12.48	10.65
1710hrs	29.00	13.54	11.76
DAY2 0815hrs	39.50	11.555	9.908
1015hrs	38.85	11.661	9.87
1215hrs	29.80	13.404	12.05
1415hrs	27.70	13.808	12.05
1615hrs	19.20	15.445	13.72
DAY3 0820hrs	36.85	12.046	10.195
1020hrs	27.60	13.828	12.07
1220hrs	23.40	13.866	13.175
1420hrs	20.40	15.19	13.51
1620hrs	9.85	17.246	15.67
DAY4 1140hrs	20.25	15.243	13,566

Table 4.8: Moisture Content and computed GCV and NCV for Closed glass Dryer

Date & Time (Hours)	Moisture Content in Closed Steel Dryer (%)	GCV (MJ/Kg) CV (Gross)	NCV (MJ/Kg) CV (Net)
DAY1 0910hrs	48.10	9.879	7.89
1110hrs	44.8	10.51	8.58
1310hrs	32.5	12.58	11.07
1510hrs	29	13.54	11.76
1710hrs	28	13.75	11.99
DAY2 0815hrs	35.3	12.88	11.078
1015hrs	32.87	12.81	11
1215hrs	34.94	12.41	10.58
1415hrs	31.8	13.019	11.22
1615hrs	30.95	13.18	11.39
DAY3 0820hrs	28.55	13.645	11.88
1020hrs	19.45	15.397	13.72
1220hrs	24.9	14.348	12.622
1420hrs	12.7	16.697	15.099
1620hrs	16.1	16.04	14.409
DAY4 1140hrs	20.25	15.243	13,566

Day & Time	Moisture Content in Closed Steel Dryer (%)	GCV (MJ/Kg) CV (Gross)	NCV (MJ/Kg) CV (Net)
1340hrs	13.65	16.514	14.9
1600hrs	5.40	18.103	16.581
DAY5 900hrs	11.65	16.9	15.13

Day & Time (Hours)	Moisture Content in Closed Steel Dryer (%)	GCV (MJ/Kg) CV (Gross)	NCV (MJ/Kg) CV (Net)
1340hrs	10.4	17.131	15.556
1600hrs	5.45	18.103	16.581
DAY5 900hrs	10.75	17.07	15.495

The results are then displayed graphically in fig 4.7 For the glass dryer and in figure 4.8 for the steel dryer

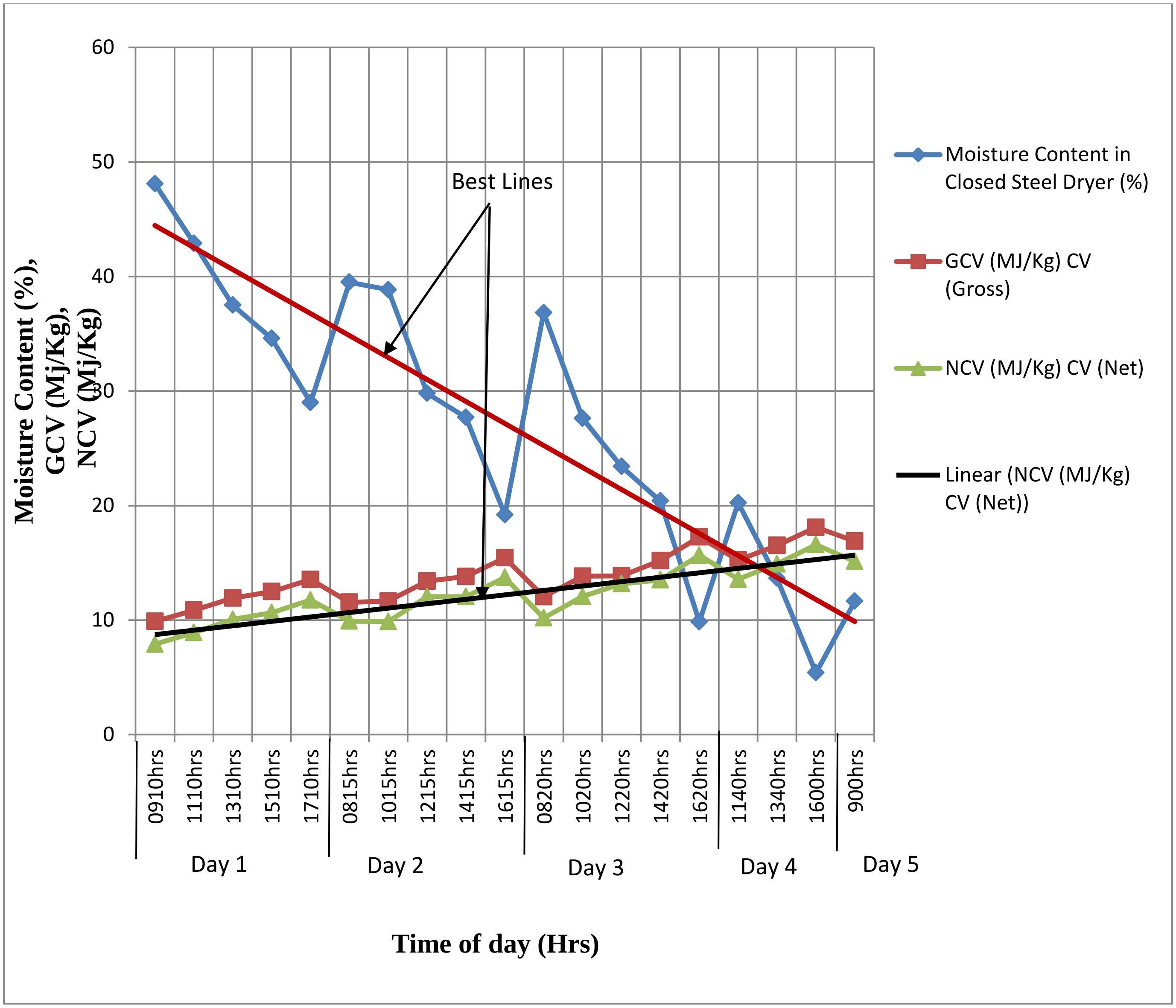

Figure 4.7: Percentage Moisture Content Reduction, GCV and NCV versus time for closed glass dryer

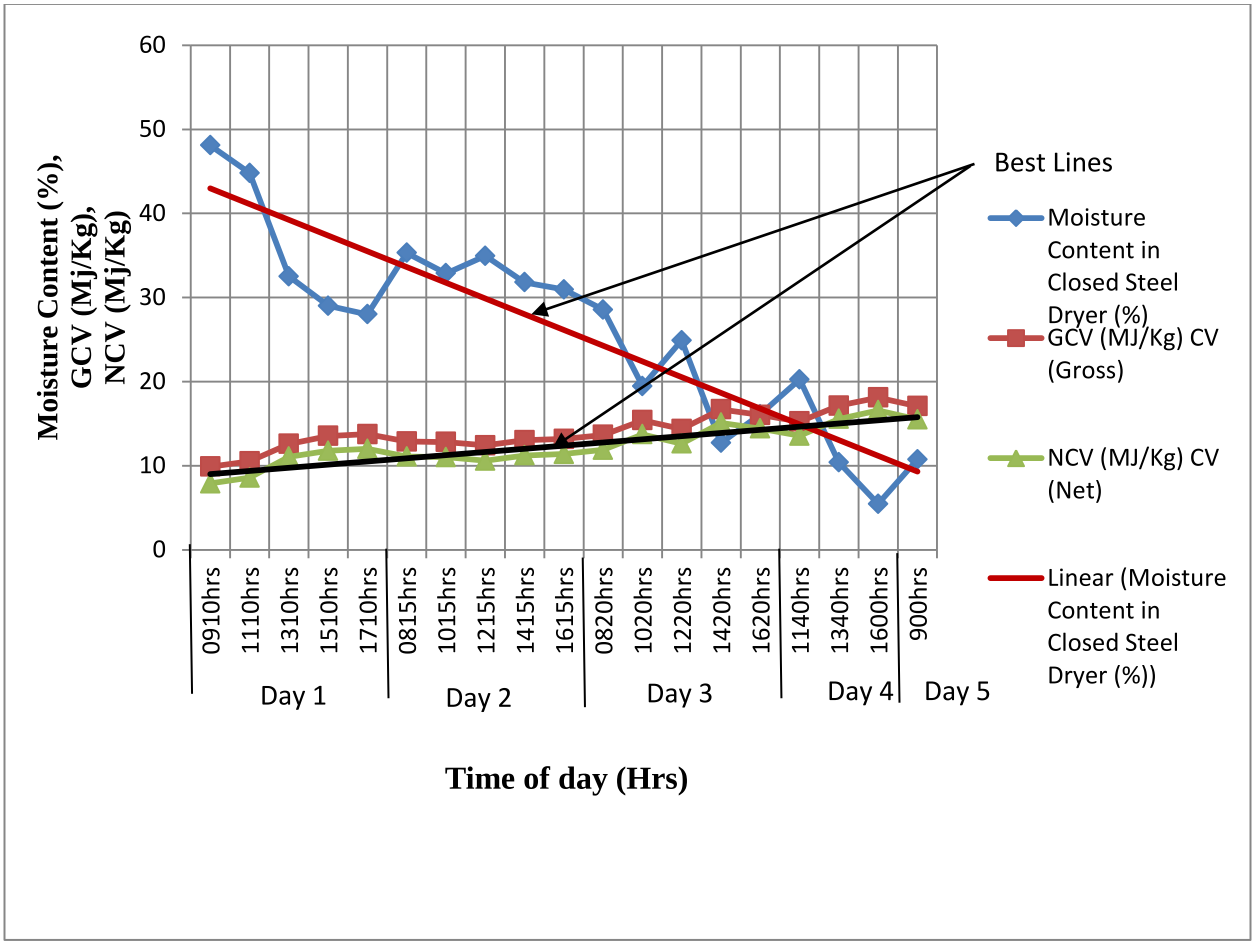

Figure 4.8: Percentage Moisture Content Reduction, GCV and NCV outplay versus drying time for Closed steel dryer.

According to Fig 4.7 and 4.8 the reduction in the moisture content in both the glass and steel dryer is observed to have an effect of increasing the GCV and the NCV. The glass dryer gives a maximum GCV of 18.103MJ/Kg and a corresponding NCV of 16.581MJ/Kg. The steel dryer gives similar values of maximum GCV and NCV as the glass dryer, indicative of the fact that, the maximum calorific values obtained during continuous drying is independent of the type of dryer.

After the third day of drying there was no significant changes in the rate of moisture reduction signifying the equilibrium point beyond which the bagasse was observed to actually disintegrate to powder .

4.4 Moisture reduction and Change of GCV and NCV.

From the continuous drying of the sample bagasse ,the calculated results of the GCV and NCV against the moisture content are tabulated in the table 4.9 and portrayed in figure 4.9.

Table 4.9: GCV and NCV for the Varying Moisture Content

Moisture Content (%)	GCV kJ/kg	NCV kJ/kg
50	9514	7525
48.1	9880	7911
40.05	11343.7	9454
29	13558	11789
20.40	15214	13535
16.10	16042	14409
5.4	18103	16581

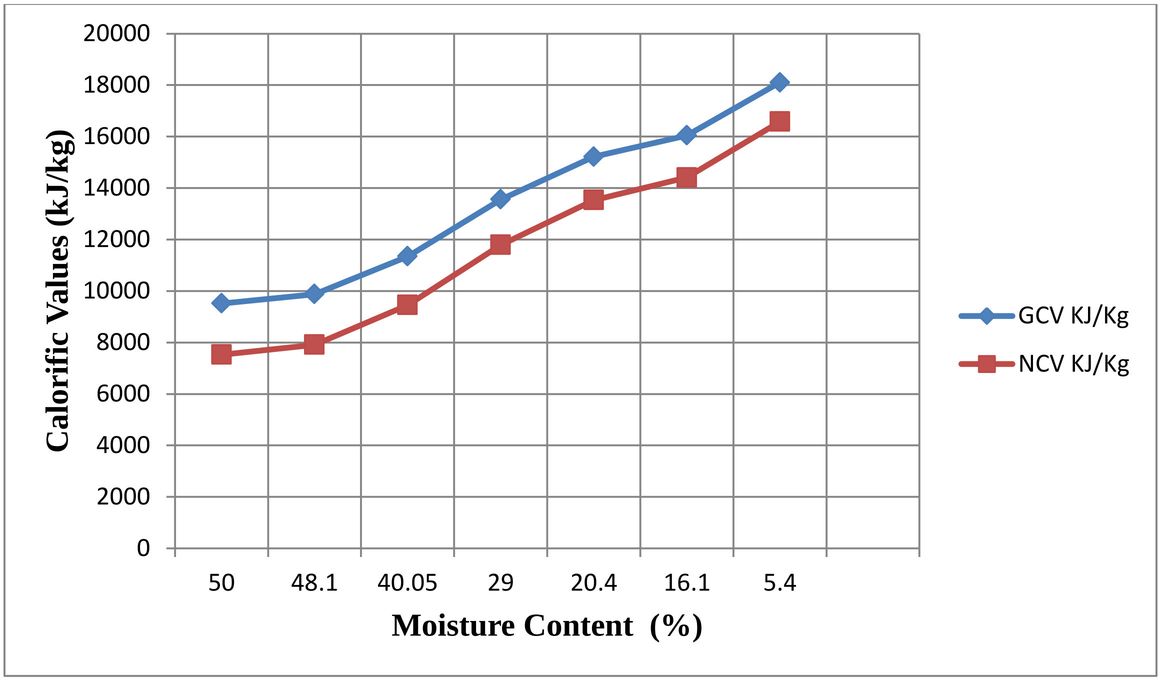

Figure 4.9: Rate of Change of GCV and NCV

At 50% moisture content the GCV is 9514 kJ/kg while NCV is 7525 kJ/kg and at 5.4% moisture content the GCV is 18103 kJ/kg while NCV is 16581kJ/kg. These are slightly less than the generally accepted values of dry ash free bagasse of 19400kJ/kg for GCV and 19254 kJ/kg for NCV (Hugot, 1986) due to the assumption that the sucrose percentage is constant while in reality it changes after sometime into complex sugars.

Experimentally it has been reported that bone dried bagasse presents a GCV of 19268.0 kJ/kg while at 50% (w.b) it is about 7563kJ/kg (Sosa – Arnao, Correa, Silva, & Nebra, 2006). In another research, bone dried bagasse presented a GCV of 17632 kJ/kg while at 50% moisture content and NCV of about 8816 kJ/kg (Barroso et al, 2003; Ghosh, 2005).

It is deduced that drying of bagasse results in higher combustion temperature, thus improving boiler efficiency by reducing the load on the induced draft fins. (Upadhiaya, 1991). Previous experiments also confirms that such drying could also reduce both air pollution and air demand in the furnace (Boulet, 1976) while it has been shown that drying can increase the efficiency of the boiler (Edwards, 1981).

4.4 Potential Benefits of Solar Drying

From the design parameters of the cogeneration boiler as given in section 2.9.2 and from the results in appendix 3 for bagasse totals, steam and power generated, it can be deduced that cogeneration boiler 170 tonnes uses 70 tonnes of bagasse to run at optimum. Therefore from this we can deduce that;

1 Tonne of bagasse = 2.428 Tonnes of Steam – (4.3)

Using the data from Appendix 3, on 1st October, 565MWh of energy was produced at bagasse moisture content 50%.

Since 1 MWh is produced by 2 Tonnes of Bagasse, it therefore means;

565MWh will be produced by 1130 Tonnes of Bagasse – (4.4)

Using equation (4.3) into equation (4.4) we have;

1130 Tonnes of bagasse = 2744.28 Tonnes of Steam per day or 113Tonnes of steam per hour (4.5)

From equation (4.4) the energy per hour will be

545MW/24 = 23.54MW/hr. (4.6)

Combining equation (4.5) and (4.6) it can be deduced that 113 Tonnes of steam/hour would give 23.4MWh of energy.

Therefore 4.85 Tonnes of Steam = 1MWh (4.7)

4.5.1 When Dried for Seven (7) Hours

At 50% the GCV and NCV are equal to 9514kJ/kg and 7525kJ/kg respectively. At 41% moisture obtained after drying for seven hours the GCV and NCV are 11267kJ/kg and 93528kJ/kg respectively.

From equation 4.4, when 1130 Tonnes of bagasse of 9514 kJ/kg (GCV) was burned in the boilers energy of 565MWh was generated. It therefore means when the same amount of a gas 1130 Tonnes of 11267kJ/kg (GCV) is burnt the energy generated would be 668.98MWh. It can then be deduced that drying of bagasse by seven hours will result in burning less bagasse to produce the same amount of power or burning the same amount of bagasse to produce more power

CHAPTER FIVE: CONCLUSION.

Open air drying of bagasse for six to seven hours a day, improves potential utilization of bagasse as the moisture content will be reduced by 8% to 9% resulting in burning less bagasse to produce more energy. Open drying also reduces net air emission of particles and volatile organic compound (VOCS) for the amount of steam produced depends on the combustion of bagasse.

Open dryers give higher overall higher moisture content reduction with a maximum of 12.95% for glass dryer and 12.05% for steel dryer compared to closed dryers which give 8.6% reduction moisture content for closed glass dryer and 8.35% for closed steel dryer.

During continuous drying of bagasse the equilibrium point of about 10% moisture content was attained in both the glass and steel dryers after three days

It was concluded that both open and closed dryers are equally effective in open air drying in sugar industries as they both attain maximum GCV of 18103kJ/kg and NCV of 16581kJ/kg.

.

References

Abdel-Rehim, Z. S., & Nagib, Z. A. (2007). Solar drying of bagasse pulp. *Journal of Applied Sciences Research*, *3*(4), 300–306.

Arrascaeta, A., & Friedman, P. (1987). Bagasse drying. *International Sugar Journal*, *89*, 68–71.

A Silva, M., & Nebra, S. A. (1997). Numerical simulation of drying in a cyclone. *Drying Technology*, *15*(6-8), 1731–1741.

Bacon, L. R., & Otrahaler, J. V. (1954). Extra Pol for Reducing the Sugar Losses in Bagasse. *The Sugar Journal*, *17*, 32–36.

Barbosa, R. D. (1992). *Sugar cane bagasse drying in a pneumatic system.* (MSc. Degree). State University of Campinas, São Paulo, Brazil.

Barroso, J., Barreras, F., Amaveda, H., & Lozano, A. (2003). On the optimization of boiler efficiency using bagasse as fuel☆. *Fuel*, *82*(12), 1451–1463.

Boulet, W. P. (1976). *Dryer system*. Google Patents. Retrieved from http://www.google.com/patents/US3976018

Cárdenas, G., Devazquez, D. P., & Wittwer, E. (1994). Energy and Exergy analysis of a combined bagasse dryer-boiler system. *International Sugar Journal*, *96*(1146), 213–219.

Corrêa, J. L. G., Graminho, D. R., Silva, M. A., & Nebra, S. A. (2004). The cyclonic dryer: a numerical and experimental analysis of the influence of geometry on average particle residence time. *Brazilian Journal of Chemical Engineering*, *21*(1), 103–112.

Correia, L. E. M. (1983). Bagasse drying. *Seminário de Avaliação Do Bagaço–São Paulo Sopral–Sociedade de Produtores de Açúcar E Álcool*, 1–15.

Das, P., Ganesh, A., & Wangikar, P. (2004). Influence of pretreatment for deashing of sugarcane bagasse on pyrolysis products. *Biomass and Bioenergy*, *27*(5), 445–457.

Devahastin, S., & Mujumdar, A. S. (1999). Batch drying of grains in a well-mixed dryer-effect of continuous and stepwise change in drying air temperature. *Transactions of the American Society of Agricultural Engineers*, *42*(2), 421–425.

Downing, C. M., Hobson, P. A., Kent, G. A., & Burbidge, D. (2002). Is investment in a bagasse dewatering mill economically justifiable for cogeneration? In *Proceedings of the Australian Society of Sugar Cane Technologists (ASSCT)* (Vol. 24, pp. 347–353). PK Editorial Services; 1999. Retrieved from http://www.assct.com.au/media/pdfs/2002_pa_m4.pdf

Edwards, B. P. (1981). Bagasse drying. In *Proceedings of Australian Society of Sugar Cane Technologists* (pp. 203–206). Australian Society of Sugar Cane Technologists.

Ekechukwu, O. V., & Norton, B. (1999). Review of Solar-Energy Drying Systems II: An Overview of Solar Drying Technology. *Energy Conversion and Management*, *40*(6), 615–655.

Energy Regulatory Commission. (2011). *Updated Least Cost Power Development Plan (2011-2031)*.ERC. Retrieved from http://www.renewableenergy.go.ke/downloads/studies/LCPDP-2011-2030-Study.pdf

Farines, J. H. (1976). Pre-drying bagasse using flue gases. *Proceedings New Series. American Society of Sugar Cane Technologists*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US19810591214

Ghosh, D. K. (2003). Bagasse burning principle and care. In *Proceedings of the 65th Annual Convention of the Sugar Technologists' Association of India,* (pp. E13–E20). Bhubaneshwar, Orissa, India: Sugar Technologists' Association of India. Retrieved from http://www.cabdirect.org/abstracts/20033196719.html

Global Wind Energy Council (GWEC). (2013). *Global Wind Report: Annual Market Update 2013*.

Hossain, M. A., & Bala, B. K. (2002). Thin-layer drying characteristics for green chilli. *Drying Technology*, *20*(2), 489–505.

Hugot, E. (1986). *Handbook of Sugar Cane Engineering* (3rd ed.). Elsevier Science.

KenGen. (2012). 59th Annual Report & Financial Statements. KenGen. Retrieved from http://www.kengen.co.ke/documents/2011KenGenAnnualReport&FinancialStatements.pdf

Kenya Institute for Public Policy Research and Analysis (Ed.). (2009). *Kenya economic report, 2009: building a globally competitive economy*. Nairobi, Kenya: Kenya Institute for Public Policy Research and Analysis.

Kerr, E. W., & Nadler, H. A. (1911). *Bagasse drying*. Agricultural Experiment Station of the Louisiana State University and A. & M. College.

Kinoshita, C. M. (1989). *Flue-gas drying of bagasse*. Hawaii Natural Energy Institute, University of Hawaii at Manoa. Retrieved from http://www.osti.gov/scitech/biblio/6796653

KPLC. (2016). Kenya Power Annual Report and Financial Statements. KPLC. Retrieved from http://www.kenyapower.co.ke/tender_docs/ANNUALREPORTANDFINANCIALSTATEMENTS2014-15EMAIL.pdf

KPLC. (2012). Kenya Power Annual Report and Financial Statements. KPLC. Retrieved from http://www.kenyapower.co.ke/tender_docs/ANNUALREPORTANDFINANCIALSTATEMENTS2011-12EMAIL.pdf

Manohar, R. P. J. (1997). *Industrial utilization of sugar and its co-products*. New Delhi, India: ISPCK Publishers and distributors.

Massarani, G., & Valença, G. C. (1981). Sugar Cane Bagasse Drying. In *III National drying meeting* (p. 355).

Massarani, G., & Valença, G. C. (1983). Bagasse drying. *Seminário de Avaliação Do Bagaço–São Paulo Sopral–Sociedade de Produtores de Açúcar E Álcool*, 1–15.

Meirelles, A. J. A. (1984). *Cane bagasse drying in a fluidized bed.* (MSc. Degree Dissertation). State University of Campinas, São Paulo, Brazil.

Ministry of Energy. (2012). *Feed-In-Tariffs Policy on Wind, Biomass, Small-Hydro, Geothermal, Biogas and Solar Resource Generated Electricity*. Ministry of Energy, GOK. Retrieved from http://www.energy.go.ke/downloads/FiT20Policy,202012.pdf

Ministry of Energy, GOK. (2012, May 11). National Energy Policy Third Draft. Retrieved from http://www.kplc.co.ke/fileadmin/user_upload/Documents/05-2012/Media/National_Energy_Policy_-_Third_Draft_-_May_11_2012.pdf

Ministry of Planning and Development (MoPND), & Ministry of Economic and Social Council (MESC). (2007). *Kenya Vision 2030, A Globally Competitive and Prosperous Nation* (1st ed.). Government Press. Retrieved from http://www.researchictafrica.net/countries/kenya/Kenya_Vision_2030_-_2007.pdf

Mittal, B. L. (2005). Importance of bagasse drying and development of a design for a workable bagasse dryer. *Eight Joint Convention of Three Associations (India)*, E22–E28.

Nebra, S. A., & Macedo, I. de C. (1989). Pneumatic drying of bagasse. *International Sugar Journal*. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US201302660960

Paturau, J. M. (1988). Alternative Uses of Sugarcane and its Byproducts in Agroindustries. *FAO Animal Production and Health Paper*. Retrieved from http://www.fao.org/livestock/agaP/Frg/AHPP72/72-24.pdf

Ramaiah, N. A., Srivastava, S. K., & Tewari, L. P. (1979). A Composition for Reducing the Pol and Moisture in Bagasse - Sushira. *Proceedings of Sugar Technologist Association of India*, *43*, 49–75.

Roos, C. J. (2008). *Biomass Drying and Dewatering for Clean Heat & Power*. Northwest CHP Application Center. Retrieved from http://www.academia.edu/download/31037090/biomassdryinganddewateringforcleanheatandpower.pdf

Salermo, M., & Santana, O. (1986). Economic aspects about bagasse dryer. *El Instituto Cubano de Investigaciones Azucareras (ICINAZ) report.(5)*, 44–49.

Sánchez Prieto, M. G., Carril, T. P., & Nebra, S. A. (2001). Analysis of the Exergetic Cost of the Steam Generation System of the Cruz Alta Mill. In *Proceedings of the 16 th Brazilian Congress of Mechanical Engineering (COBEM)* (pp. 206–215).

Sharma, A., Chen, C. R., & Lan, N. V. (2009). Solar-energy drying systems: A review. *Renewable and Sustainable Energy Reviews*, *13*(6), 1185–1210.

Sokhansanj, S., & Jayas, D. S. (1995). Drying of foodstuffs. *Handbook of Industrial Drying*, *1*, 589–626.

Sosa-Arnao, J. H., Correa, J. L., Silva, M. A., & Nebra, S. A. (2006). Sugar Cane Bagasse Drying- A Review. *International Sugar Journal*, *108*(1291), 381.

Sosa-Arnao, J. H., & Nebra, S. A. (2009). Bagasse Dryer Role in the Energy Recovery of Water Tube Boilers. *Drying Technology*, *27*(4), 587–594.

SREP, GOK. (2011, May). Scaling-up Renewable Energy Program (SREP) Draft Investment Plan for Kenya. Retrieved from http://www.renewableenergy.go.ke/downloads/policy-docs/Updated_SREP_Draft_Investment_Plan_May_2011.pdf

Syahrul, S., Hamdullahpur, F., & Dincer, I. (2002). Energy analysis in fluidized-bed drying of large wet particles. *International Journal of Energy Research*, *26*(6), 507–525.

Toei, R., Okazaki, M., & Tamon, H. (1994). Conventional Basic Design for Convection or Conduction Dryers. *Drying Technology*, *12*(1-2), 59–97.

Toshniwal, U., & Karale, S. R. (2013). A review paper on Solar Dryer. *International Journal of Engineering Research and Applications*, *3*(2), 896–902.

United Nations (Ed.). (2002). *Report of the World Summit on Sustainable Development: Johannesburg, South Africa, 26 August-4 September 2002*. New York: United Nations.

Upadhiaya, U. C. (1991). Bagasse as a fuel. *International Sugar Journal*, *93*(1111), 132–138.

Vijayaraj, B. (2009, January). *Studies on Bagasse Drying* (Ph.D. Thesis). Anna University, Chennai, India.

Vijayaraj, B., Saravanan, R., & Renganarayanan, S. (2006). Energy and exergy analysis of sugar cane bagasse drying. *Proceedings of Advances in Energy Research-AER-2006, Chennai, Anna University*, 77–82.

Whitfield, D. E. (2000). Solar dryer systems and the Internet; Important resources to improve food preparation. In *Proc*.

Yarnal, G. S., & Puranik, V. S. (2010). Energy Management Study in Sugar Industries by Various Bagasse Drying Methods. *Strategic Planning for Energy and the Environment*, *29*(3), 56–78.

Appendix-1 Working Instruction on Determination of Bagasse Moisture (wb) (%)

1. Weigh the empty sieve dish to determine its weight on the Avery Berkel weighing Balance Hl-230. Aa.
2. Add a bagasse sample of 100g on the dish.
3. Weigh the dish and the bagasse to get (Ab) the weight before drying.
4. Put the bagasse dish into the moisture oven S. No. 11/972462 type p.f. 200.
5. Set the oven temperature at 106^0c for four hours.
6. After four hours remove the dish and weigh again to determine the weight (Ac).
7. The % reduction of the moisture content is thus calculated as Ac – Ab

Appendix-2 Daily reports and Calculated values.

BAGASSE PROJECT DATA SHEET

DATE: 29/6/2012

PHYSICAL PROPERTIES AND CHARACTERISTICS OF BAGASSE

Sample Moist Mass (Mb) ______**10.24**__________kg

Initial Moisture Content (Mi) ______**50.05**___________%

Final Moisture Content (Mf) ______**41.45**___________%

Average Moisture Content (Ma) ______**45.75**___________%

Sample Dried Mass (Md) ______**8.832**___________kg

Water Evaporated Mass (Mw) ________-____________kg

Average Wind Speed (W) ________-____________m/s

Thickness ______________________**100**______________ mm

Time (H)	Min Temp (^0c)	Max Temp (^0c)	Relative Humidity (%)
09:30	-	-	-
10:30	34	35.7	62
11:30	35	40.3	43
12:30	37	44.2	31
13:30	38	53.3	26
14:30	39	50.6	2
15:30	37	47.8	10
16:30	32	43.8	14

Appendix-3 Factory Data for MSC for October 2012

Date	TCH/IMB			Bagasse Totals - Cogen	Power Generated (MW)	Steam Generated (per day)
	Morning	Afternoon	Night			
1st	2650/1021	2691/971	-	1130	565	2712
2nd	2780/977	2426/960	2701/1191	1296	648	3110.4
3rd	2673/1048	2300/821	1625/514	1240	620	2976
4th	-	-	413/124	268	134	643.2
5th	2769/928	2327/949	39/51	1010	505	1212
6th	1726/587	2672/933	2713/985	886	443	2126.4
7th	2757/989	2796/992	2640/1181	208	104	416
8th	-	-	1236/339	1140	570	2736
9th	2562/821	2595/826	2613/905	1254	627	3009.6
10th	2711/978	2743/722	593/139	538	269	1291.2
11th	-	-	-	734	367	1761.6
12th	320/47	2656/791	971/281	302	151	724.8
13th	-	-	-	-	-	-
14th	-	-	-	-	-	-
15th	-	2022/595	2421/844	-	-	-
16th	2470/914	2730/980	-	1036	518	2486.4
17th	2727/969	2508/762	2595/466	1248	624	2995.2
18th	1515/494	2274/708	2259/601	918	459	2203.2
19th	1415/460	2141/604	1896/473	940	470	2256.0
20th	1346/467	2446/1013	1833/548	948	474	2275.2
21st	441/153	2060/525	2265/586	-	-	-
22nd	2656/816	2809/902	2223/653	1232	616	2956.8
23rd	2439/1049	2444/913	1661/376	998	499	2395.2
24th	-	527/126	2002/930	558	279	1339.2
25th	2496/988	2815/1205	2278/810	-		

26th	2676/1032	2752/1140	2258/950	1280	640	3072
27th	2638/711	2676/660	1209/304	1232	616	2956.8
28th	-	-	1891/594	448	224	1075.2
29th	2212/394	2678/816	1980/637	1130	565	2712.0
30th	2029/579	2761/574	1517/255	762	381	1828.81
31st	-	-	-	-	-	-

Source: Mumias Sugar Company, October 2012

Appendix-4 Weather Data for MSC 21st June 2012

Time	AT (^{0}c)	ATMAX (^{0}c)	ATMIN (^{0}c)	HRS SUN (hr)	Rain (mm)	RH (%)	SOL RAD (W/m^2)
8:00	22.6	22.6	22.1	0.17	0	74.9	48.57
8:10	23.1	23.2	22.6	0.17	0	75.1	84.62
8:20	23.5	23.5	23.1	0.17	0	71.7	72.72
8:30	23.7	23.8	23.4	0.17	0	67.4	105.11
8:40	24	24	23.6	0.17	0	66.2	88.64
8:50	24.4	24.7	23.9	0.17	0	67.6	102.27
9:00	24	24.3	24	0.17	0	64.4	79.77
9:10	25	25.3	24	0.17	0	55.3	118.55
9:20	25.2	25.3	24.8	0.17	0	51.6	125.87
9:30	25.1	25.3	24.9	0.17	0	52.1	121.3
9:40	25.3	25.6	25.2	0.17	0	52.7	97.79
9:50	25.2	25.5	25.1	0.17	0	51.8	63.58
10:00	25.3	25.4	25.2	0.17	0	54	61.66
10:10	24.8	25.2	24.8	0.17	0	55.9	55.53
10:20	25.2	25.3	24.8	0.17	0	53.8	58
10:30	25.3	25.3	25	0.17	0	52.5	76.29
10:40	25.6	25.6	25.4	0.17	0	52.6	81.32
10:50	26	26.3	25.6	0.17	0	57.8	105.93
11:00	25.6	25.9	25.6	0.17	0	53.5	105.2
11:10	25.6	26.1	25.6	0.17	0	49.9	87.18
11:20	25.5	25.9	25.5	0.17	0	54.6	57.26
11:30	25.8	25.8	25.2	0.17	0	54.6	61.11
11:40	25.4	25.7	25.3	0.17	0	55.2	49.76
11:50	25.4	25.8	25.4	0.17	0	53.6	46.75
12:00	25.2	25.6	25.2	0.17	0	56.8	44.37
12:10	25	25.3	25	0.17	0	58	35.04
12:20	24.8	25	24.8	0.17	0	60.6	27.35

12:30	24.7	24.8	24.7	0.17	0	62.7	37.87
12:40	24.4	24.6	24.2	0.17	0	64	29.55
12:50	24.8	24.8	24.4	0.17	0	61.5	50.22
13:00	25.1	25.4	25	0.17	0	57	51.32
13:10	25.2	25.3	25	0.17	0	56.9	50.5
13:20	24.5	25.2	24.5	0.08	0	57.5	25.71
13:30	24.4	24.7	24.4	0.1	0	59.4	25.71
13:40	24.5	24.5	24.3	0.12	0	62.5	27.99
13:50	24.5	24.6	24.4	0.17	0	60.9	31.1
14:00	24.3	24.6	24.3	0.17	0	64.2	27.81
14:10	23.8	24.2	23.8	0	0	67	15.83
14:20	21.6	23.8	21.6	0	0	71.8	8.78
14:30	19.4	21.1	19.4	0	0	80.1	10.79
14:40	19.3	19.4	19.3	0	0	78.4	8.51
14:50	19.1	19.2	19	0	0	80.5	3.57
15:00	18.8	19	18.8	0	0	82.3	0
15:10	18	18.7	17.9	0	0	92	1.1
15:20	17.5	17.8	17.4	0	0	99.6	2.56
15:30	17.3	17.4	17.2	0	0	100	0.37
15:40	17.2	17.4	17.2	0	0	100	0
15:50	17.1	17.2	17	0	0	100	0
16:00	16.9	17.1	16.9	0	0	100	0
16:10	17.1	17.1	17	0	0	100	0
16:20	17.1	17.2	17	0	0	100	0
16:30	17.2	17.2	17	0	0	100	0
16:40	17.5	17.5	17.2	0	0	100	0
16:50	17.3	17.3	17.2	0	0	100	0
17:00	17.5	17.5	17.3	0	0	98.5	0

Source: Kenya Meteorological Station Headquarters, Nairobi 2012