DRYING OF AGRICULTURAL PRODUCTS BY GEOTHERMAL HEAT IN KENYA

BY

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DECLARATION

This research paper is my original work and has not been submitted to any learning institution for a degree or examination.

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

DEDICATION

This work is dedicated to my wife Lindah Nasipwondi, my daughter Kayleen, my mum Rosemary, Mzee Khamala family and all my friends.

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ABSTRACT

The main objectives of this work were to carry out a prefeasibility study on the use geothermal heat in drying of agricultural product in Kenya and design of a geothermal drying system for a selected crop at a preferred site. The study used the yearly data from the ministry of agriculture, livestock and fisheries to obtain the quantity of each of the main cash and food crops in the Kenya. The data of these crops from 2010 to 2014 was used to make a comparison on the line graph. It was found that maize crop was produced in the largest quantity within these years. The comparison in maize production in all the counties in Kenya was done on the line graph using yearly data from the ministry of agriculture, livestock and fisheries. Trans-Nzoia, Nandi, Uasin-Gishu, Narok, Bungoma, Nakuru, Kericho, Bomet, Kakamega and Vihiga were found to be among the highest maize producing counties in Kenya. The temperature, chemistry and flow rates for main geothermal fields in Kenya were obtained from the geothermal update reports. Eburru, Menengai and Olkaria geothermal fields were chosen as the key fields for because of their closeness to the maize producing areas. The maize drying requirements and technical analysis for maize was obtained from food processing and engineering literature. It was found that the best maize drying conditions were 43℃ temperature and 55.5% equilibrium relative humidity. The design of geothermal maize drying system was designed using maize drying requirements obtained from literature and climatic conditions of Nakuru area where the key geothermal fields were selected. In the design, the approximate amount of geothermal fluid required to dry a batch of 35 tonnes of maize per batch was obtained. The economic analysis for this sample dryer was done to determine the viability of the project. The net present value was found to be $82784, simple payback period was 5years, 1 months and 1 day and the internal rate of return 18% were the decision making tools used in determinations of the economic feasibility of the project.

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1.0 INTRODUCTION

1.1 Background Information

1.1.1 Geography of Kenya

Kenya is an Eastern Africa country bordering Uganda, Tanzania, Somali Ethiopia and Indian Ocean. It lies within 1.00N and 38.00E coordinates occupying total surface area of 580,367 Sq. Km out of which 569,140 Sq. km is land while the remaining 11,227 Sq. km is water bodies. The climatic conditions are predominantly tropical climate along the coast region and some parts in the interior to semi-arid in most parts of northern, eastern and north eastern regions. The terrain is characterized by low plains rising towards the central highlands which are separated by the Great Rift Valley. The most fertile plateaus lie to the west of the rift valley. The lowest point of the country is the Indian Ocean at 0 M altitude while the highest point is at the peak of Mount Kenya at 5,199 m altitude. Some of the natural resources existing in Kenya includes: Wildlife, Gemstone, and Soda ash, Fluorspar, Gypsum, Diatomite, Salt, Zinc and Limestone.

Agricultural activities take about 48.1% of the total land use of which 9.8% is used as arable land, permanent crop and pasture occupies 0.9% and 37.4% of the agricultural land use respectively. Forest cover occupies about 6.1% of land while the remaining 45.8% of land is for other uses such as buildings and settlement. The total land under irrigated agriculture is about 1030 Sq. km. Agriculture takes a larger portion of water use at 79% while domestic and industrial use accounts for about 17% and 4% respectively. Kenya is a signatory to some of the key world environmental agreements such as Kyoto-protocol, desertification, marine dumping and marine life conservation, Ozone layer protection among other agreements. The Kenya's central highlands are among the highly agriculturally productive regions in Africa while the peak of Mt. Kenya is the second highest point Africa after the peak of Mt. Kilimanjaro.

1.1.2 Economy

Kenya has been termed as the economic and transport hub of east African region according to CIA World Facts Book Report (2015). In the past years, the GDP of the country has been growing at 5% making it a lower middle class economy country. The economic growth and poverty reduction in the country has been hampered by the over reliance on primary goods and increased corruption in key service institutions. Despite the highest number of people who have attained basic education, unemployment rate still stands at 40%. Agriculture sector contributes about 25% of the country's total GDP employing about 80% of the Kenya's population. The small scale farmers contribute to about 75% of the total agricultural production in the country (Ministry of Agriculture, Livestock and Fisheries, 2015). The GDP (purchasing power parity) has been increasing from \$127.5 billion, \$134.3 billion and \$143.1 billion in 2013, 2014 and 2015 respectively. At the same time, the real GDP growth rate has also been increased from 4.7%, 5.3% and 6.5% in 2013, 2014, and 2015 respectively. The GDP per capita has also increased from \$3,000, \$3100 and \$3300 in 2013, 2014 and 2015 respectively. The main agriculture products in the country are tea, coffee, corn, wheat, sugarcane, fruits, vegetables, dairy products, beef, fish, poultry and eggs. The industrial growth rate by 2015 was at about 6.1%. The country's population under the poverty line was about 43.4% by 2012.

1.1.3 Energy Situation in Kenya

The Kenyan commercial energy sector has been dominated by petroleum and electricity. In traditional sector, rural community and urban poor communities depend on wood fuel to meet their energy needs. According to (Kiplagat, Wanga, & Li, 2011), Wood fuel and other biomass fuel accounts for approximately 70% of the primary energy consumption. Petroleum and electricity represents 23% and 6% of the total primary energy consumption respectively. The remaining energy sources such coal accounts only 1% in the energy mix as represented on the figure below.

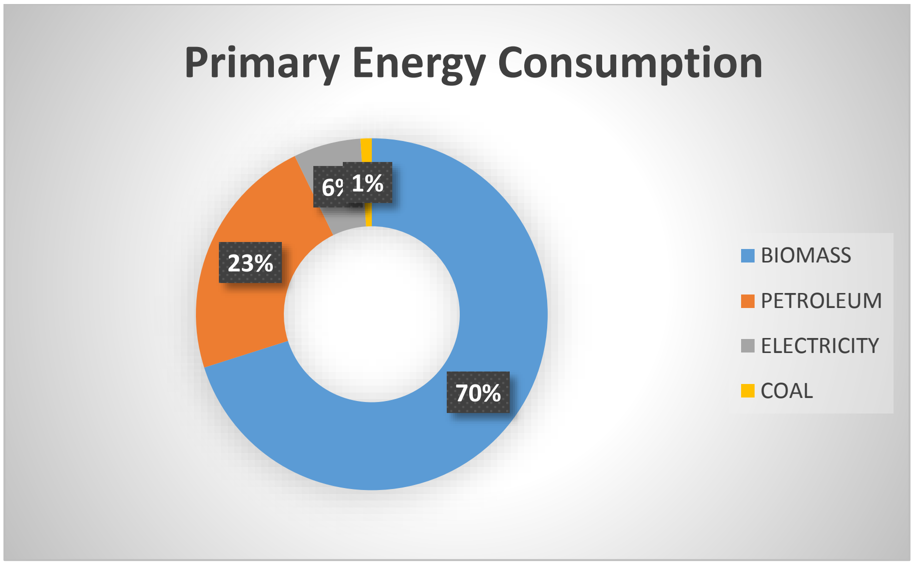


Figure 1 Total Primary Energy Consumption in Kenya (Omenda, Silas, & Muchemi, 2014)

According to Omenda (2014), the primary energy consumption in Kenya is 121kWh per capita. In drying sector, solar energy is predominantly used. Solar energy is used for heating and lighting purposes. The installed electricity capacity in the country comprises of hydro sources 820MWe, fossil fuel powered plants at 776MWe, Geothermal Plants at 573MWe and wind at 69.5MW as represented in the figure below.

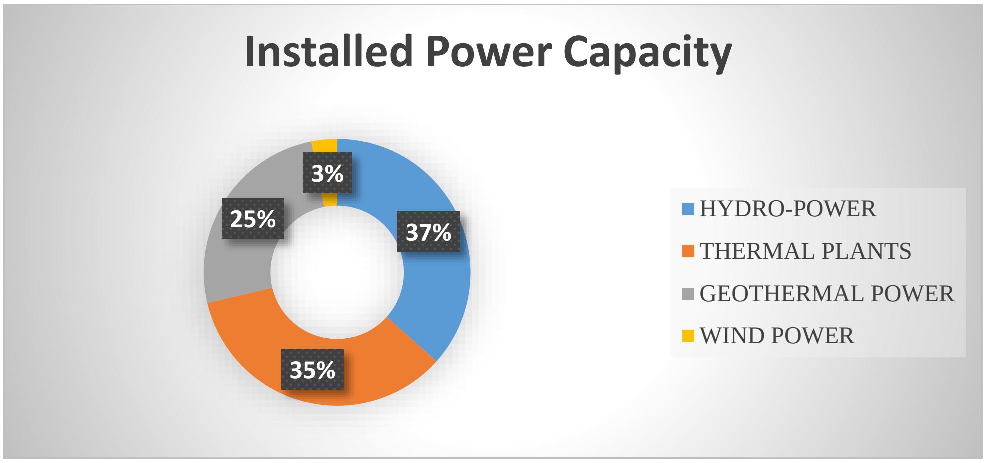


Figure 2 Installed Power Capacity in Kenya (Omenda, Silas, & Muchemi, 2014)

According to energy consumption per sector, residential sector takes the largest portion at 78%. Agriculture and forestry accounts for 1% of the total energy consumption per sector. This implies that agricultural sector hasn't invested in the use of modern energy. This has led to over reliance on conventional method of production and post-harvest activities.

The energy consumption per sector in Kenya is indicated as in the figure below:

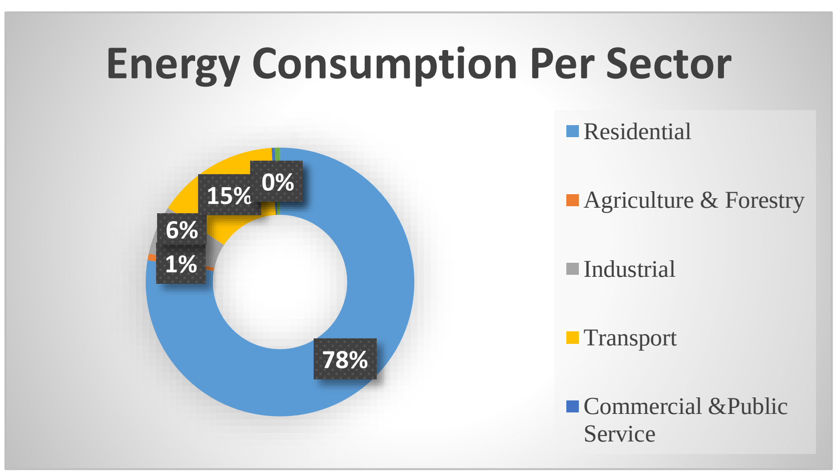


Figure 3 Energy Consumption per Sector in Kenya (Kiplagat, Wanga, & Li, 2011)

The country imports most of its fossil fuels. The graph below represents petroleum fuels imports in Kenya from 2005 to 2012.

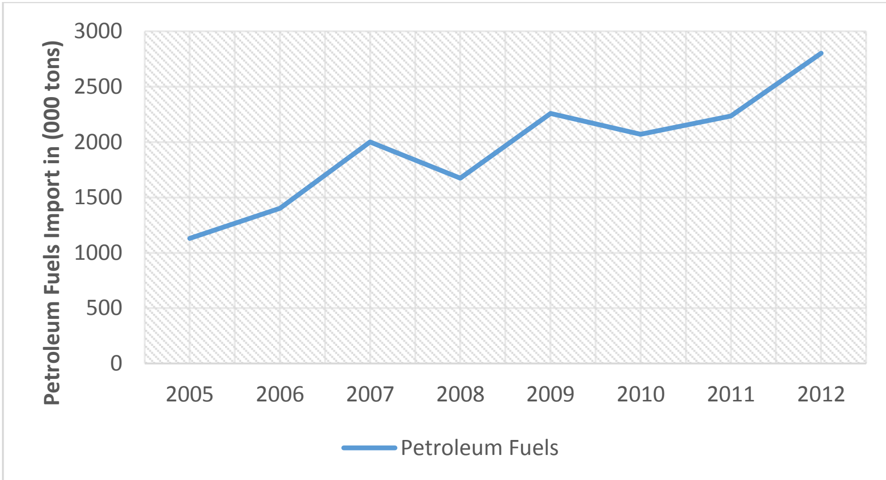


Figure 4 Petroleum Fuels Import in Kenya (Mureithi, 2013)

1.2 Problem Statement

According to (GDC & USAID, 2013), Agricultural sector is rated as the highest contributor to the country's Gross Domestic Product (GDP). The report by FAO (2011) indicated that agriculture accounts for 24% of the total domestic income in Kenya. The agricultural sector is said to offer about 75% of both direct and indirect employment to population. The total government revenue, raw materials for local industries and foreign exchange earns 45%, 75% and 50% of their total earnings from Agriculture according to the USAID report of 2013.

Maize grains moisture content is between 20-28% at harvesting. Any moisture content above 20% and water activity of >0.6 offers best environment for growth of moulds, yeast, enzymes and bacteria which produces aflatoxin over drying causes oxidation and browning according to (Kang'ethe, 2011) as shown in the figure 5 below:

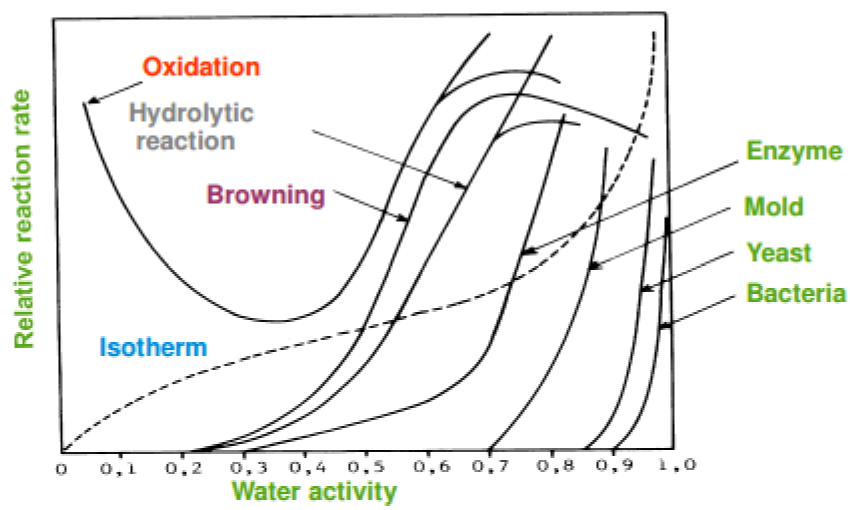


Figure 5 Effect of water activity on grain quality (Kang'ethe, 2011)

The ministry of agriculture report (2013) stated that deterioration of harvested crops due to poor weather, aflatoxin infestation and microbial attack on grains as the some of the major challenges in crop production in Kenya. (Ministry of Agriculture, 2013). The aflatoxin poisoning cases caused by grains contamination in Kenya recorded in past years include 331 in 2004, 75 in 2005, 20 in 2006, 4 in 2007 and 5 in 2008. The most recent data on aflatoxin cases have not been documented but there have been several sources from media sources (Kang'ethe, 2011). The current crop drying methods such as sun drying, solar drying and fossil fuel driven drying have been found to be slow, non-uniform drying, expensive and not environmental friendly (Tonui K. S., Mutai, Mutuli, Mbuge, & Too, 2014). Most small scale farmers heavily rely on sun drying method which takes more time to attain equilibrium moisture content during drying and dependent on ambient solar conditions which are unreliable. In addition, the effective solar hours for drying in Kenya are just 4 hours a day as found by Tonui et al, 2014.Some grain handling industries use fossil fuel driven dryers for uniformity and reliability in drying (Kinyanjui, 2013). Fossil fuels have however become unaffordable by many grain farmers due to increasing global oil prices. In addition, burning of fossil fuels leaves negative carbon foot prints on the environmental causing global warming. The use of electricity for drying purposes is expensive due to higher oil prices used thermal system. It was also noted to be unreliable due to ever fluctuating rain patterns which affect generation of hydropower which currently contributes a larger portion of electricity in the mix (Mburu, 2010). Therefore, there is need for a more reliable drying system which is economically and environmentally sustainable. The use of geothermal heat for drying has been seen as the remedy to drying challenges in Kenya

1.3 Justification

According to (Van Nguyen, Arason, Gissurarson, & Palsson, 2015) geothermal energy is a renewable, clean and sustainable source of energy derived from the center of the earth. The report continues to indicate the earth's inner core has temperatures of about 5000℃, while the outer core has temperature of about 4000 °C. (REN, 2015), ranked Kenya as number 8 in the world in terms of geothermal energy use. Researches have also shown that Kenyan rift along the East African rift valley has high potential of geothermal resource (Mariita, 2010). Crop producing regions in Kenya are so close to geothermal energy fields and prospects thus making use of geothermal heat in drying relatively cheaper in terms of transportation of agricultural products to the drying center.

According to Maier & Bakker-Arkema (2002), the optimum drying temperatures for the grains depend on species of the grain being dried and the grain quality requirements. Rough rice in cross flow dryers requires 100°F (40°C) while feed corn requires the highest drying temperatures of 43 to 49℃) under the same conditions (Bakker-Ekerma, 2002). These optimum drying temperatures lie within the geothermal resource temperatures for most fields in Kenya. Menengai geothermal field for example exhibits temperatures in the range of 190-200℃ in shallower liquid dominated reservoirs and more than 300℃ in deep reservoir (Alfredo, 2015). The results from Eburru

Geothermal fields have indicated temperatures ranging from 193℃ to 279℃ at the depths beyond 3000m (Mwangi, 2012). The conceptual models done at Olkaria Geothermal fields have indicated temperatures range of 150℃ to 300℃ at the depth of 1200m, 225℃ to 375℃ at the depth beyond 2400m (Axelsson, 2013).

The drying heat can also be generated from brines leaving the separator in case of high temperature geothermal fields. The data from the already existing geothermal power plants in Olkaria field indicates that Olkaria 1 power plant separates geothermal fluid at 6bar pressure. The brine flow rate at 220 tonnes per hour. The separation pressure at Olkaria 1 additional unit (v) separates at 10 bars and the flow rate of 470 tonnes per hour. Olkaria (II) power plant has a flow rate of 750 tonnes per hour at separation pressure of 6 bars. Olkaria (IV) power plant has a separation pressure of 11 bars. The brine chemistry according to Mburu, 2010 indicated that scaling occurs when the brine is cooled below 110℃. The geothermal drying system utilizes binary technology cycle with a working re-injection which doesn't emit greenhouse gases (Pierre & Nikos, 2010). As shown in the table below:

Source	Pollutant			
	CO_2	SOX	NOX	PM
Coal	994	4.7		
Oil	758	5.5		
Natural Gas	550	0.1		
Geothermal			0	0
Flash cycle	27	0.16		
Binary cycle	0	0		

Table 1 Gas Emissions from Different Energy Technologies (Pierre & Nikos, 2010)

The environmental emissions and the cost of explorations and drilling can be avoided when brine is being used. This implies that only the cost of the dryer system components, labour costs and operation and maintenance costs are to be considered in the analysis. The drying system will also create several employment opportunities to the local community. Therefore, utilization of geothermal resource for drying of agricultural products can be socially, economically and environmentally sustainable (Mburu, 2010).

1.4 Objectives

1.4.1 General objectives

The main objectives of this study were:

1. To carry out a pre-feasibility study on drying of agricultural products using geothermal heat in Kenya.
2. To design a model geothermal maize drying system.

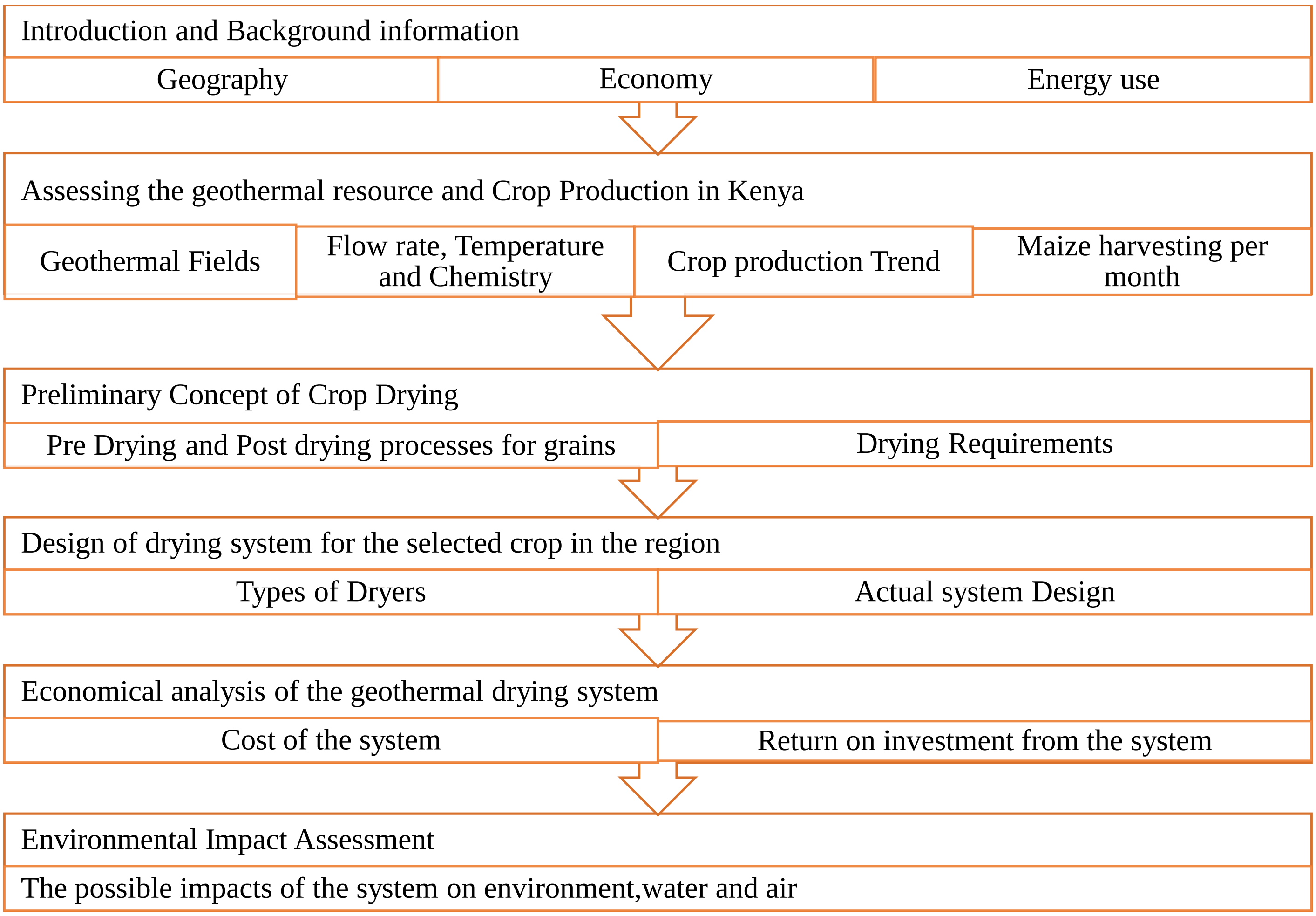
1.4.2 Specific objective

In order to achieve the two main objectives above, the study aims at achieving the specific objectives as stated below:

1. To identify the candidate agricultural products in Kenya those require drying both entirely or regionally.
2. To analyze and rank the identified products to be dried basing on the volume of each product and the resource use.
3. To evaluate the geothermal energy fields and prospects in Kenya that can be used in agricultural products drying.

2.0 PROJECT DESCRIPTION

This study used several research methods in order to achieve the set objectives. The work in the study was done in phases as shown in the diagram below.



Descriptive qualitative and quantitative research methods were used to describe the geography, economy and energy use situation in Kenya. These data information were obtained from the government reports, journals, and periodicals. This gave the actual economic, energy and geographical situations in Kenya. The market range for the geothermal drying project was established by determining the amount agricultural products produced in Kenya over the years. The data used was taken from the ministry of agriculture report from 2010 to 2014. The comparison in crop production was done on the line graph to determine which crop had the highest production. The highest product was considered for design work. The production of the agricultural products considered for design per county was also established and comparison made on the line graph. Lastly, the quantity of the crop harvested per month was also found to estimate the dryer capacity requirements and other related logistics.

The data for resource assessment for the selected geothermal field was both primary and secondary data. Geological, geochemistry, Geophysical and Hydrogeological data was obtained at from the documented reports and periodicals. This study was done on all the geothermal resource fields and prospects in Kenya. The brine and condensate from the already established power plants was also considered as the source of heat for drying. The best geothermal field was selected depending on its closeness to the agricultural product considered for drying. The climatic parameters such as daily and monthly temperatures, humidity patterns and wind speed were obtained from the renewable energy technology (RET) screen software (Minister of Natural Resources Canada, 1997-2013). These conditions were helpful in design of the system since drying process is highly depended on the ambient climatic conditions.

Overview of the preliminary drying concepts and processes were obtained from literature review from bio system design and drying books, scientific papers and journals. The standard industrial drying practices and requirements were obtained through literature review. Specific energy consumption in drying of the selected agricultural products was also obtained through literature review. The high and low moisture content acceptable for several agricultural products for drying was obtained from the scientific papers. The drying temperature requirements for different agricultural products were found in the scientific journals.

Different drying modes based on the flow of the materials being dried in relation to the flow of drying air i.e. countercurrent, cross-flow and concurrent were discussed. The analysis was then done to establish the suitability each method in drying the selected agricultural material. The merits, demerits and design considerations of different convective type of dryers as recorded in scientific papers were discussed. Considering several factors such as the specific heat energy consumption, uniformity in drying, drying air temperatures requirement and the optimum drying capacity requirement, the best dryer suitable for the selected product drying was chosen.

The layout scheme for the three possible geothermal system scenarios i.e. use of geothermal steam directly from production well, use of condensate from the power steam turbine and finally use of the brine from the separator was drawn using Microsoft Visio software.

The drying system for the selected product was then done using the Engineering Equation Solver (EES) software. The parameters and the constants needed in the design of the of the geothermal drying system included geothermal fluid temperature inside the tube, drying temperature required, heat transfer coefficients, geothermal fluid heat convection coefficient, heat exchanger and pipe thermal conductivity, air heat convection coefficient, constants in Nusselt number calculations, heat exchanger pipe diameter and total length, air thermal conductivity, air kinematics viscosity, geothermal fluid flow rate, air mass density among other parameters.

The capital cost of setting up the geothermal drying system was estimated. The expenditure included purchasing of the drying system equipments such as dryers, pipes, heat exchangers and the labour costs for laying out the system were all included in the capital costs. The operation and maintenance costs of the system were also estimated which includes possible purchase of geothermal fluid per year, annual maintenance costs and salaries for the operators. The amount of money saved when using geothermal resource in drying of agricultural products instead of using other sources of energy was determined. The comparison was then made to see whether the project can operate at a profit or on a loss.

Finally, the environmental impact assessment of the project was done. This was to establish the possible human and environment impacts when using geothermal energy in agricultural product drying.

3.0 LITERATURE REVIEW

3.1 Crop Drying

3.1.1 Crop Drying Basics

According to (Kinyanjui, 2013), agricultural products drying is one of the oldest methods in food preservation industry. Most farmers have been preserving their main food such as meat, fish, fruits and grains through drying and smoking to meat and fish to attain food sustainability even in seasons when food supply is low (Brennan, 2006). Drying technologies and equipments ranges from sun drying and hot air drying which are simpler to high capacity and highly sophisticated drying methods such as freeze drying and spray drying. Drying process has several advantages according to (Maharjan, 1995). These advantages found by Maharjan (1995) include reduction of moisture content to improve the shelf life, reduction of undesirable enzymatic reactions which may destroy the chemical content, reduction in growth of moulds and hence lowers the possibility of aflatoxin generation. Dried products also have an economic value as it reduces the transport, packaging and storage costs.

Drying causes vaporization of the liquid from the wet stocks when heat is simultaneously supplied on it. The heat transferred into the stock ought to be equal or high than the heat of vaporization. In case the heat supplied is less than the heat of vaporization, the temperatures of the material drops thus causing unstable drying process (Untung, 2007). In situations when the heat supplied is higher than the heat of vaporization, the temperatures of material rises causing hardening, colour changes and other chemical reactions associated with high temperatures. The drying heat can be supplied by either: Convection for direct dryers, conduction for indirect or contact dryers, and radiation by placing the wet product into the micro wave or radio frequency electromagnetic field. Studies have shown that about 85% of the all the industrial dryers use convective mode of drying. In this mode, they use hot air or direct combustion gases as drying medium (Tesha, 2006).

Drying process when not well controlled may cause changes both on the quality and physical appearance of the drying material (Bekker-Arkema & Fred, 2002). Shrinkage during drying changes the shape and the sizes of solid materials. Colour and texture for the dried products are inferiors compared to those of the fresh products. Volatile flavor in food materials evaporates during uncontrolled drying thus causing changes in flavor and reduction in nutritional value (Brennan, 2006).Therefore, the drying process should be closely monitored to avoid these effects. In his studies, Kinyanjui (2013) found out that drying can be subdivided into four main categories. These categories include: low temperature drying which uses unheated air, medium temperature drying which uses temperatures below 43℃ for seed grains and 60℃ for milling grains, high temperature drying mostly in animal feeds with temperatures maintained at 82℃ and finally the combination of both low temperature and high temperature drying according to Bekker-Arkema & Fred (2002).

Drying involves simultaneous transfer of mass and heat across the drying materials and drying air boundaries. The moisture inside the drying materials is removed by both the sensible and latent heat entering the food to cause evaporation (Guillermo & Rotstein, 1997). The convective heat transfer method transfers heat from the drying air to the surface of the drying material while conductive heat transfer method transfers heat from the surface to the inside (Chen & Hernandez, 1997). Heat can also be transferred directly by conduction to the interior when the food materials are placed on the heated surface. Radiant, microwave and radio frequency may also be used in dehydration but it has been limited. Moisture can also be removed in ice form through sublimation process when food material is frozen through freeze drying technology. This can be done in very low pressure drying environments. Osmotic drying involves immersing the agricultural materials in a hypertonic solution causing water to move from the materials into the solution by the use of osmotic pressure (Brennan, 2006).

3.1.2 Psychometrics in grain drying

Drying of grains involves transfer of moisture and heat simultaneously. The medium in which these transfers occur is air. Therefore, physical air properties such as relative humidity (humidity ratio), specific volume, enthalpy and dry bulb temperatures should be known or determined.

The definitions of some of these air physical properties are as discussed below:

a. Relative humidity (RH)

This is the ratio of vapour pressure of water molecules in the air to the saturated vapor pressure of the same air measured at the same temperature expressed as a percentage.

b. Humidity ratio (moisture content)

The mass of water vapour per unit mass of dry air in kg/kg of dry air.

c. Dry bulb temperature

This is the temperature of air measured by the ordinary thermometer. It is used in determination of relative humidity of the air at a given point. It is expressed in degrees centigrade.

d. Enthalpy

This is the energy content of moist air per unit mass of dry air expressed in kilojoules per kilogram of dry air. The enthalpy of air before heating and the required enthalpy of air after heating can be used in determination of size of dryer.

e. Water activity (a_w)

This is the ratio of the partial pressure of water in food material to the partial pressure of water in the atmosphere at the same temperature. The formula for calculation of water activity in drying is given in the equation below:

$$a_w = \frac{p'_w}{p_w} \qquad 1$$

Water activity can also be expressed in terms of relative humidity as given in equation 2 below

$$a_w = RH/100 \qquad 2$$

Food products should be dried to water activity below 0.6 in order to inhibit bacterial growth.

3.1.3 Grain Drying in Heated Air

The heat is transferred by convection to the surface of wet material when placed in hot drying air. A stream of air the carries away the water vapour that is formed at this stage. Assuming that the humidity, temperature and velocity of the drying air are maintained constant, and all the heat from the drying air is absorbed by the materials being dried.

3.1.4 Moisture Movement

The heated air passing through the grains increases the vapour pressure of the grain being dried and the temperatures of the grains. The vapour pressure on the surface of the grain rapidly increase immediately the grains are exposed to the drying air. At the same time, the temperature at the center of the grain increases slowly causing the moisture content from the Centre of the grain is absorbed into the mass of the drying air.

This moisture removal process can be summarized as shown in the figure below:

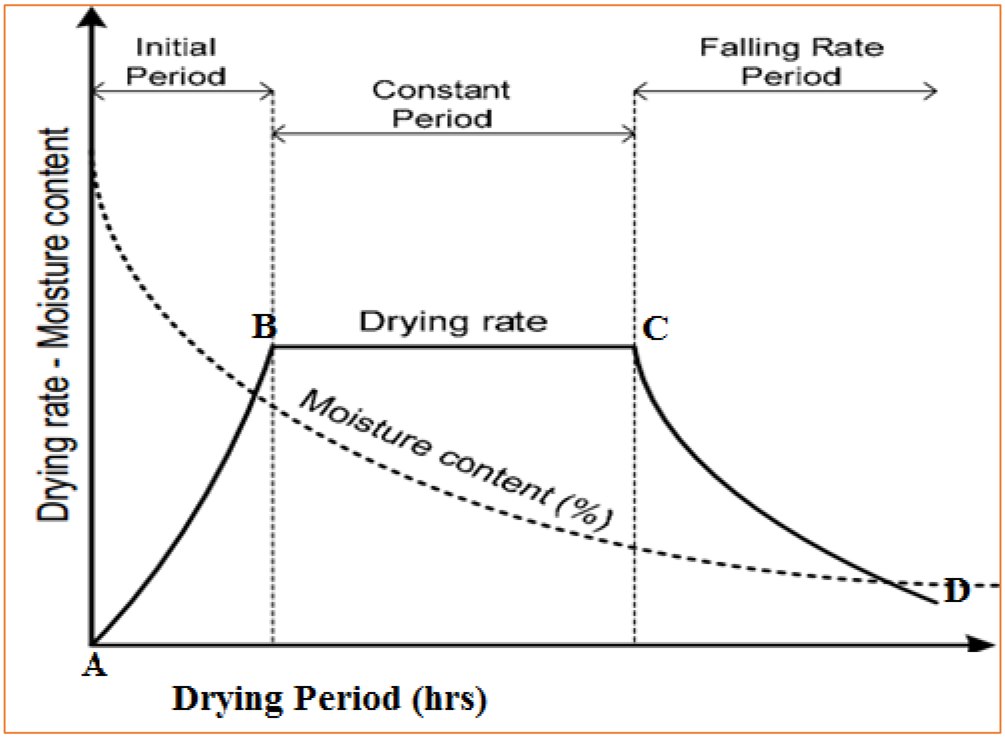


Figure 6 Drying curve for a wet solid in heated air at constant temperature, humidity and air velocity. (Brennan, 2006).

The initial period is also known as the equilibrium or settling down stage A-B. At this stage, the wet material comes in equilibrium with the drying air. The drying rate is faster as within the shorter time as the surface water is evaporated as it comes in contact with the drying air. The period is shorter compared to the entire drying period B-C. The surface of the material is saturated with moisture at constant rate drying stage. Water evaporating from the surface of the material is immediately replaced by the water moving from within the material towards the surface. This thus keeps the surface of the materials always saturated. This stage is characterized with constant drying rate and surface temperature corresponding to the wet bulb temperature of the air. As drying continuous, the amount of water moving the surface of the material may not be enough to maintain saturation thus leading to a decline in drying rate in the falling rate period. The point at the end of constant period and the start of the falling rate period is mostly known as critical point C. The temperatures on the surface of the material increases towards the dry bulb temperatures of the air after this critical point. This signifies the end of the drying cycle. This period should be managed and monitored carefully to avoid heat damage (Brennan, 2006).

In deep bed drying, the heat transfer is by convection method. Srivastava and John (2002), stated that there will always be temperature and moisture content gradient in deep bed drying. In the research, it was found that these gradients vary with the position in the bed and the time. The transfer of heat and moisture in convective maize dryers by diffusion can be termed as negligible in comparison to the transfer by convection. Heat and mass flow between the drying air and the grains in deep bed drying is said to be in non-equilibrium state. Therefore, this models can be presented in coupled ordinary, partial and differential equations which can be numerically solved.

In development of deep bed drying models, the following assumptions have to be considered according to (Srivastava & John, 2002).

- There is a negligible volume shrinkage during drying.
- The temperature gradient inside the grain as well as particle to particle heat conduction is negligible.
- The bin walls are adiabatic with negligible heat capacity.
- The heat capacities of moist air and grain are constant during short time periods.
- An accurate thin layer equation is known.

Development of the deep bed models, a differential volume (Adx) is considered to be positioned at point (x) at drying time (t) in a controlled volume bed. The drying air moisture content, temperature and enthalpy can found as a function of bed height and time.

In their research, (Sadaka & Bautista, 2016) stated that moisture moves from the wet grains to the drying air when the vapour pressure in the drying air is less than the vapor pressure inside the grain kernel. This difference in vapour pressures causes the movement of moisture from the interior of the product being dried to the surrounding air before being released to the atmosphere. The drying agent can either be heated air or natural air being forced through the volume of the wet materials being dried. The grain drying rate is affected by the temperature, flow rate and relative humidity of the drying air (Lee & Sup, N/A). Increase in the air volume and drying air temperatures passing through the dryers can substantially increase the drying rate. However,extremely high temperatures causes rapid drying which may result in stress and cracking of the grain kernels. Therefore, it is recommended that the temperature and the relative humidity of the drying air should be monitored in order to avoid stress build up during drying.

Depending on the moisture content of the grain at harvesting, Sadaka and Bautista (2016), recommended the minimum air flow rate needed per tonne of maize being dried.

Their recommendations are shown in the table below:

Moisture Content (% Wet Basis)	Minimum Flow Rate (M^3/hr) per tonne of maize
11 to13	34
13 to 15	68
15 to 18	136
18 to 20	204
20 to 22	272
22 and above	408

Table 2 Moisture content levels and recommended Flow rates (Sadaka & Bautista, 2016)

3.1.5 Equilibrium Relative Humidity

This can be defined as the relative humidity attained in the dryer when the drying materials neither losses nor losses water content. After drying, the air at the grain will attain some conditions whereby there is no moisture movement either from the grains to the air or vice versa. The air will be at equilibrium relative humidity while the grain will attain the equilibrium moisture content.

The equilibrium relative humidity can be denoted as:

$$\mathrm{ERH} = 100\mathrm{a_w} \qquad (3)$$

Where $\mathrm{a_w}$ = water activity

Water activity can be expressed as:

$$\mathrm{a_w} = \frac{\text{Vapor pressure of water exerted by food}}{\text{Saturated vapor pressure of water at the same temperature}} \qquad (4)$$

In this design, the water activity was calculated from the formula blow:

$$a_w = 1 - \exp[-\exp(0.914 + 0.5639 \ln MC_{Final(db)})] \qquad 5$$

Where $MC_{Final(db)}$=Dry basis moisture content. The final moisture content dry basis for maize in this design was found to be 13.6%. Using this value, the water activity was found as 0.555. Therefore, the equilibrium relative humidity (ERH) was is 55.5%. This equilibrium relative humidity will be set as the relative humidity of the air leaving the dryer. This is the relative humidity where there will be no loss of moisture from the maize grain to the air of vice versa thus minimizing shrinkage and kernel breakage (Hurburgh, Bern C, & Brumm T, 2008).

The graphical figure below shows the equilibrium moisture contents for maize grains at different relative humidity and temperature conditions:

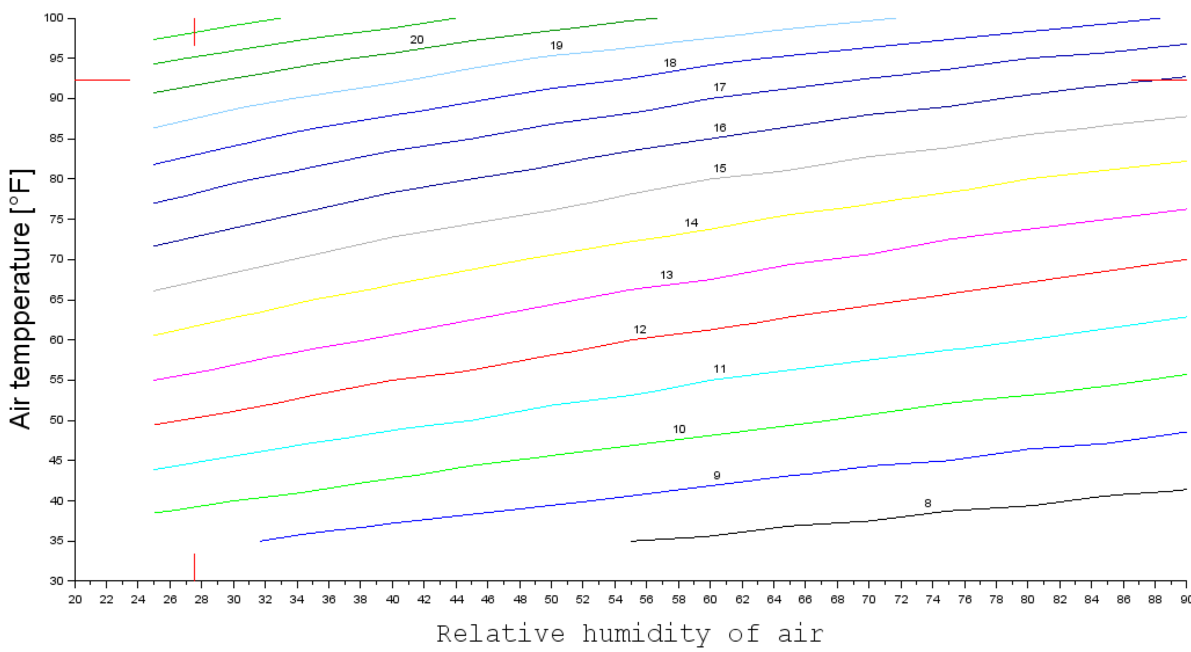


Figure 7 Equilibrium Moisture Content at Different Temperature and Relative Humidity (Sadaka & Bautista, 2016)

The equilibrium moisture content should be considered to ensure the dried maize is stored in favorable conditions to prevent them from reabsorbing moisture from the ambient air. The time duration in which the dried maize can be stored before contamination depends on the equilibrium moisture content attained after drying and the ambient environmental conditions where the maize grain is being stored.

3.1.6 Porosity values

These values can be defined as the fraction volume of air volume space which is presented as the ratio of the void volume to the total volume. The porosity value can easily be calculated as the volume fraction of air. Indirectly, it can be found using the relationship between bulk density, true density and porosity. Most researchers have found the porosity for maize to range from 37% to 47.6% depending on the maize variety and the moisture content (Lee & Sup, N/A).

3.1.7 Forced air flow

The forced air system is needed to increase the flow of heated air through the column of maize grains. The volume of the air passing through grains being dried depends on the on the air flow resistance (static pressure) and the type and size of the fan being used. The static pressure developed in the column of drying grains depends on the moisture content of the grains, velocity of air, depth of grains, and foreign matter present in the grain column. Experiments have shown that the fan power rating and the static pressure determines the volume of air that can be delivered by the fan at a certain time (Sadaka & Bautista, 2016).

The drying ability of the heated air depends on supplied air flow rate and the ability of the air to absorb and hold water from the wet materials. The ability of the fan to blow air through a certain column of maize grains depends on the static pressure which is the pressure that should be provided by the fan to overcome the resistance of air flow through the column of grains and the design of the fan (Hellevang, 2013).

The table below shows the estimates of static pressures for various air flow rates in cubic meters per hour per tonne ((m3/hr)/ton) of clean grains at different grains depths in (m) in bin drying system

Grain	Depth (M)	Air flow rate in cubic metres/ hr per tonne of grain			
		204.0	340.0	408.0	544.0
Maize (Shelled Corn)	1.2	127	202	232	338
	1.8	249	421	526	735
	2.4	401	834	1059	1756
	3.0	685	1358	1806	3300
	3.6	1079	2155	2782	5443
Wheat	1.2	281	461	560	810
	1.8	585	944	1333	1856
	2.4	1059	2055	2653	40.48
	3.0	1930	3300	4546	6912
Barley	1.2	192	311	361	523
	1.8	361	660	839	1258
	2.4	660	1258	1656	3051
	3.0	1058	2180	3051	4546
Soya beans	1.2	110	152	192	249
	1.8	189	316	391	585
	2.4	301	599	822	1158
	3.0	486	1009	1283	1930
	3.6	720	1198	1915	3051

Table 3 Static Pressures at Different air flow rates and grain depth (Hellevang, 2013)

There are two types of fans that are mostly used to blow the dry air through the column of grains for drying. Vane-axial fans supply high volume flow but low pressure difference. They are therefore more preferably used in shallow-depth bin drying systems. They are generally low in initial costs but very noise in their operation. Centrifugal fans have less volume flow but high pressure difference. They are therefore more applicable in drying systems that require relatively high volumes of drying air. They also operate with low noise compared to fan axial fans. However, the performance of these fans reduce as the static pressure increases. Coating of fan blades with dust, lubricants and other foreign materials also reduces the fan performance (Gardisser, NA).

The fan motor rating depends on the static pressure in pacals needed and the amount of air to be heated and supplied.

The table below shows the volume of heated air in (m^3/min) that can be supplied by fan motor of a rated capacity in kW to overcome a specific static pressure in Pascal.

Fan Motor (Kw)	Static Pressure in Pascal									
	0	249	498	745	995	1244	1493	1742	1991	2240
3.7	203.9	198.2	189.9	178.4	167.1	155.7	141.6	124.6	107.6	70.8
5.6	307.3	297.3	286.0	266.2	253.4	233.6	212.4	188.3	162.8	106.2
7.5	410.6	396.4	382.3	354.0	339.8	311.5	283.2	252.0	218.0	141.6
11.2	474.3	460.1	446.0	417.7	403.5	375.2	346.9	317.1	284.6	226.5
14.9	538	523.9	509.7	481.4	467.2	438.9	410.6	382.3	351.1	311.5.

Table 4 Typical Centrifugal Fan Air Delivery in Cubic Meters per Minute (Sadaka & Bautista, 2016)

3.1.8 Drying temperature

Drying temperatures affect the nutritional quality and physical appearance of the grain. Therefore, drying temperatures vary depending on the grain variety and the purpose for which the grain will be used for after drying. The grains used as animal feed can be dried in high temperatures without affecting their nutritional value. Researches have shown that the germination rate drops whenever the kernel grain temperatures increases beyond a certain temperature level. Extremely high temperatures affect the chemical structures of the grains intended for flour milling. High temperatures and drying rates can cause cracking and shrinking of the grain coats. The maximum recommended drying temperatures is also dependent on the type of dryer used (Hellevang, 2013).

The drying temperatures in the dryer design depends on the crop variety being dried and the dryer types.

The table below shows the recommended drying temperatures in ℃ for different grains based on their final use and the dryer type.

Grain	Dryer Type				Seed
	Cont. Flow	Rec. Batch	Column Batch	Bin Batch	
Corn	93	93	82	49	43
Wheat	66	66	57	49	43
Barley	49	49	43	43	43
Pinto Beans	32	32	32	32	32
Oats	66	66	57	49	43
Sunflower	93	93	82	49	43

Table 5 Recommended Drying temperatures (Hellevang, 2013)

3.2 Energy Efficiency and air-recirculation

It can also be expressed as specific energy consumption or drying efficiency of the dryer. According to Maier and Bakker-Ekerma (2002), energy efficiency can be defined as the amount of energy required to evaporate a pound of water from the graindrying drying process. In design of grain dryers, the compromise should be put on the rate of drying, energy efficiency and the variation of moisture across the dryer column. High drying air flow rates and low temperature combinations results in very little moisture variation across the dryer column. High energy efficiency can be achieved in a combination of high temperature and low flow rate combinations. However, low temperatures are always recommended to maintain the quality of grains during drying (Hellevang, 2013).

The drying energy requirement can be achieved by drying the grains in the field before harvesting. This however may result in field losses. Air recirculation possibility can therefore be used as a means to achieve energy saving. The drying systems with cooling air recirculation can increase the energy efficiencies by about 10% to 20%. The systems recirculating both cooling and part of drying air can increase their energy efficiency to about 30% (Hellevang, 2013).

3.3 Effects of drying on grain quality

Poor choice of drying equipment and conditions may affect the quality of the grains after drying. Some of the desirable qualities of the grains after drying include: Minimum breakage and spoilage, low moisture content which is uniform, high nutritive value, low moulds growth susceptibility, and high consumer acceptability.

The equilibrium moisture content attained during drying, determines the longevity of storage. The table below shows the equilibrium moisture content for different crops that is needed for both long term and short term storage periods.

Grain Type	Long Term (One Year)	Short Term (30 to 60 days)	
		Warm Temperatures	Cool Temperatures
Corn	12%	12%	15%
Sorghum	12%	12%	15%
Rough Rice	12%	12%	14%
Soybean	11%	11%	14%
Wheat	12%	12%	14%

Table 6 Safe moisture content for grains in long- and short-term storage (Sadaka & Bautista, 2016)

Excessive drying temperatures increase the internal kernel temperatures of the grain causing endosperm cracks. Stress cracking is also dependent on the drying rate and rapid cooling.

The recommended Kernel temperatures for different grains dried for different purposes are as shown in the table below:

Grain	End Use	Limit	
		F	C
Corn	Seed	100-110	38-43
	Dry Milling	100-110	38-43
	Wet Milling	130-140	54-60
	Feed Use	160-180	71-82
Wheat	Seed (>24% MC)	110	43
	Seed (<24% MC)	120	49
	Flour	120-150	49-66

Table 7 Grain Kernel Temperatures (Bakker-Arkema, DeBaerdemaeker, Amirante, Ruiz-Altisent, & Studman, 1999)

Excessive drying temperatures affect the grain components of sugars, gluten and proteins. This in turn lowers the nutritive value after drying. The viability of seed grains is dependent on the drying temperatures attained. The possibility growth of moulds in the grains depends on the extent of physical damage in grains, grain temperatures and moisture content of the grains. Development of moulds reduces the value of the grains and mycotoxin which is a health hazard. Poor drying also affects the color and physical appearance of the grains which are mostly perceived by the consumers.

3.4 Parameters to be controlled during drying

In research, Kinyanjui (2013) presents several factors that may influence the final quality of the dried material. These factors include: Drying rate, quality of raw material and drying temperature.

3.4.1 Drying rate

The drying rate of agricultural products depends on exposure time, initial moisture content, variety and size of the grain, air flow rate, relative humidity, air flow rate, grain depth and initial moisture content. The rise in air temperature subsequently increases the rate of drying in grains while increased air humidity lowers the rate of drying. In case of single pass in air drying, increase in exposure time increases drying rate. Air flow rate on the other hand also affects the rate of drying. However, it was noted that very fast drying rate causes shrinkage in grains and discoloration in vegetables and fruits while very slow drying causes rehydration which results in increased operation costs (Kinyanjui, 2013).

The empirical formula for grain equilibrium moisture content was shown in equation (6) below:

$$M_{eq} = 0.01 \times \left[\frac{LN(1-rh_{amb})}{-8.65\times10^{-5}\,(T_{amb}+49.810)}\right]^{\frac{1}{1.8634}} \qquad 6$$

Where: rh_{amb}=Ambient relative humidity

T_{amb}=Ambient temperature (℃)

Basing on the ambient conditions at Menengai where the proposed project is to be located the calculated equilibrium moisture content was found to be 16.7%

3.4.2 Raw material quality

Generally, agricultural products can be either hygroscopic or non-hygroscopic depending on whether they absorb moisture from air or not. The final quality of the dried material is highly dependent on the state and quality of the material it was obtained from. Fish and meat products are among the food products whose final quality depends on the raw material due to their sensitivity. For vegetables and fruits, they can be sliced in order obtain a better drying (Kinyanjui, 2013).

3.4.3 Drying temperatures

Agricultural product should be dried within their optimum drying temperatures. Extremely high temperatures results to “cooking” of the product and distortion of their chemical composition. According to Kinyanjui (2013), the optimum drying temperature for maize is about 49℃ while that one for tea is about 60℃ to 100℃ depending on the flavor intended to be achieved. For fish drying, extremely high temperatures cause case hardening. The drying temperatures control can be achieved by maintaining the relative humidity and the drying air temperatures. The drying temperature for maize seeds is 43℃ (Kinyanjui, 2013). In this design therefore, the drying temperature of 43℃ was considered to cater for both commercial milling and use as seeds.

3.5 Current Drying Methods

3.5.1 Open air sun drying

Most small scale maize farmers in Kenya spread their maize grains on the flat surface under direct sun. The grains are spread either on paved surface or mats with a grain depth of between 5cm to 15cm in an ambient weather conditions. This method has been one of the oldest and less expensive (Tonui K. , Mutai, Mutuli, Mbuge, & Too, 2014). In their research, Tonui et al (2014) further suggested that the grains should intermittently stirred the grains for uniformity in drying. The approximate drying time of more than 6 days of about 4 drying hours. In most open air sun drying experiments has shown that the drying rate of less than 0.010kg/h of the moisture was removed.

This method however, is weather dependent thus unreliable. It is also labor intensive to constantly ensure the safety and uniformity of grain drying. There are higher risks of rodents attack and other forms of contamination since there are not covered during drying. (Bakker-Arkema, DeBaerdemaeker, Amirante, Ruiz-Altisent, & Studman, 1999).

3.5.2 Crib Drying

In this method, the natural air is allowed to freely flow over the maize cobs stored in a perforated maize storage cribs. This can also be used as a storage for sometimes before shelling is done. The maize stored here at the harvesting moisture content of more than 20% and can be stored for 3 months before shelling and further drying (FAO Agriculture and Consumer Protection, 2016). The method depends on the prevailing air temperature and relative humidity for effective drying. Insect control such as weevils is a challenge because the cribs are not protected.

3.5.3 Solar Drying

The use of solar collector to heat the air before allow it to pass through the bulk or thin layer of maize by convective heat transfer. Heated air reduces the moisture and the relative humidity in the thus increasing water holding capacity (Brennan, 2006). The solar collectors are covered by a transparent glass or plastic materials to allow passage of the direct solar radiations. The short solar waves pass through the transparent cover but the long wavelength from the absorber surface cannot go through the glass cover thus creates greenhouse effect within the enclosure thus increasing the air temperature. According to (Ekechukwu & Norton, 1997), solar drying has a higher drying rate compared to direct solar drying of about 0.023kg/h of moisture removed. The grains being dried are also protected from adverse weather conditions, insect and rodent infestation and other contaminations.

The representation of the solar drying technology was shown in figure 8 below.

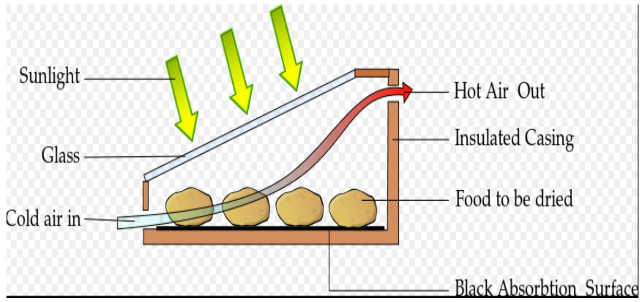


Figure 8 Solar Drying Technology (Home Place Earth, 2011)

Vijaya Venkata Raman, Iniyan, & Ranko, 2012 noted that this method is also highly dependent on the solar irradiation of the area. (Atul & Chen, 2008), cited the possibility of food discoloration when exposed to extreme uncontrolled heat, moisture condensation inside the dryer glass cover may reduce glass transmissivity as some of the main challenges in solar drying.

The formula for calculation of the useful energy from the sun that can be utilized in drying can be obtained by equation (7) below

$$E = A_C I \mu = M_a C_a (T_f - T_I) t_d \qquad 7$$

Where: E=Useful solar energy in kJ

A_c=Surface area of solar collector in m^2

I=Total global irradiation on horizontal surface during period in kJ/m^2

μ =Collector efficiency

The efficiencies of collector are said to be between 20 to 50% according to (Sodha, Bansal, Kumar, Bansal, & Malik, 1987).

M_a=Mass of air needed to remove the moisture in kg.

C_a=Specific heat capacity of air in kJ/kg℃

T_f=Temperature of air leaving the collector in degrees Celsius

T_l=Temperature of air entering the collector in degrees Celsius.

t_d=Drying time in hours

3.5.4 Fossil Fuels Use in Drying

In mechanical dryers, the drying air can be heated either directly or indirectly the use of heat exchangers. Direct heating involves the air being mixed with the heating fuel before being blown through the volume of products being dried. Indirect heating on the other hand uses the heat exchanger to heat the drying air thus the air being heated and the source of heat cannot mix. The direct heating mechanism is relatively cheaper and more energy efficient compared to the indirect heating system. However, direct heating system the fuel can cause contamination of products when they come in contact during drying. Indirect system is safer despite about 25% heat loss that may occur at the heat exchangers (FAO Agriculture and Consumer Protection, 2016).

Most of the grain handlers in Kenya use fossil fuels as a source of heat to increase the temperatures of the drying air. The heated air is then blown through the maize column. The fossil fuels used in these systems include oil, gases and coal. Oil-fired and gas-fired dryers are commonly used in on-farm drying operations. They can be applied in different dryer sizes. They are easily flexible and can be transported from one place to another. The drying rate can easily be regulated and thus achieving the uniform drying in grains.

However, fossil fuel driven dryers are relative expensive in operation and maintenance. In Lesiolo Grain Dryers for example, they dry 38metric tons of grains per hour in drying at 85℃ costs the company about USD$375,000 annually (USAID;Geothermal Development Company (GDC), 2013).Burning of fossil fuels releases greenhouse gases which contributes to global warming and other negative foot prints on the environment (Kinyanjui, 2013). The petroleum products used in Kenya is usually imported from oil producing countries. Petroleum imports were said to account for about 36% of the total imports and consuming 36% of the foreign exchange earnings (Kiplagat, Wanga, & Li, 2011).

3.5.5 Biomass fuel in drying

In most heated air dryers, oil, gas and coal are particularly used as main sources of heat. These are however conventional sources of energy which leaves carbon foot prints on the environment and expensive to most small scale operators. Biomass can therefore be used as an alternative renewable source of heating energy. The main candidates to be used as biomass in drying industries include the agricultural residues which has been underutilized and posed disposal problems.

Table (8) below contains some of the biomass materials that can be used as source of heat or drying

Material	Gross Calorific Value (MJ/KG)
Alfalfa straw	18.4
Cotton seed husks	19.4
Cotton Stalks	17.4
Ground nut shells	19.7
Maize stalk	18.2
Maize cobs	18.9
Rice straw	15.2
Soybean stalks	19.4
Sugar cane bagasse	19.0
Sorghum bagasse	18.9
Wheat straw	18.9
Wood	30.0

Table 8 Calorific Values for Different Biomass Materials (FAO Agriculture and Consumer Protection, 2016)

These residuals matters can be combust in several combustion systems. Grate furnaces are widely used combustion systems that can be used to burn a variety of residual matter. They include straws as well as particulate matter. The system allows air to circulate freely carrying heat with it. Suspension burners are suitably designed for combustion of particulate residual crop materials that have regular shape and size. Materials with relatively high moisture content can be combust in fluidized bed systems. These are however preferred in large scale operations because they are capital intensive. Gasification systems burn wood logs and particulate materials. The logs of wood are undergoes pyrolysis to generate tar and combustible gases which are used as fuel. Gasifier can achieve controlled combustion thus mostly used in direct fired drying systems (FAO Agriculture and Consumer Protection, 2016).

Tea factories under the management of Kenya Tea Development Agency (KTDA) heavily rely on biomass to heat drying air for drying and withering of tea. Tea withering takes place at the temperatures of about 85℃ for about 10 hours to reduce the moisture content to about 65%. Fermentation takes place at the temperature of 72℃ reducing the moisture content further to about 55% for about 90 minutes. Tea drying takes place at 145℃ for about 20minutes to reduce the moisture content to 3% (USAID;Geothermal Development Company (GDC), 2013).

It was estimated that most factories each tea factory under KTDA uses approximately 1,000 to 2500m^3 per month. This has caused a massive deforestation in the nearby forests thus affecting the ecosystem. The smoke released into the environment as a result of burning wood may have an impact on the environment which may contribute to climate change. The operation costs of using biomass in tea drying are relatively higher. Most of the factories are spending approximately USD$ 814,320 per year on firewood alone (USAID;Geothermal Development Company (GDC), 2013).

3.6 Geothermal Drying

3.6.1 Introduction

Agricultural products drying processes in most industrialized countries accounts to about 7-15% of the total industrial energy consumption. Most thermal dryer efficiencies are comparatively low at about 20 to 25%. In addition, these thermal dryers emit greenhouse gases which cause global warming problems. The world oil market prices constantly fluctuate thus making it less reliable. In order to minimize these challenges caused by open air sun drying methods and use of fossil fuel dryers, low to medium enthalpy geothermal resources can be used as the heating source. The low to medium enthalpy geothermal resources have the temperatures less than 150℃ . Drying needs can be met by utilizing steam from the hot water, steam of the geothermal well or recovery of heat from geothermal plants (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

The use of geothermal resource in drying is more advantageous than using fossil fuels and electricity in drying industries. The main advantage is that the geothermal hot water, steam or heat recovery from geothermal power plants is relatively cheaper and environmental friendly. The system can also be used in any weather conditions thus high reliability (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

3.6.2 Geothermal Drying Review

Geothermal heat drying has been widely used in different parts of the world. Greece developed and tested their tomato and cotton geothermal drying pilot scale system in 1991 and 1992. The heat for tomato drying was obtained from 59 ℃ geothermal hot water. The tomatoes were dried in a tunnel dryer with 25 trays with each tray holding about 7 kg of raw tomatoes. They were able to dry about 4 tonnes of tomatoes in the first year of their operation. Waste heat recovery from geothermal power plant has been used in Thailand in drying of chili and garlic. The drying temperatures for chilies and garlics are 70℃ and 50℃ respectively. The geothermal hot water at 80℃ is circulating across the cross flow heat exchanger at the flow rates of 1kg/s and 0.04kg/s for chili and garlic respectively. It took about 46 hours to dry chili while 94 hours to dry garlic. It was noted that this dryer operated at relatively lower costs and in all weather conditions (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

The former Yugoslav Republic has utilized low temperature geothermal resources in drying of rice. The rice dryer capacity of 10 tons per hour was developed operating at the heating capacity of 1360kW. The ambient air conditions of 15℃ temperature and relative humidity of 60% was heated to 35℃ at the water to air heat exchanger. The inlet temperature of the geothermal water was 75℃ while the temperature at the outlet was 50℃. In order to prevent cracking rice, the drying temperature was kept at 40℃ (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

Figure (9) below shows the schematic diagram of convective rice dryer in Republic of Yugoslav:

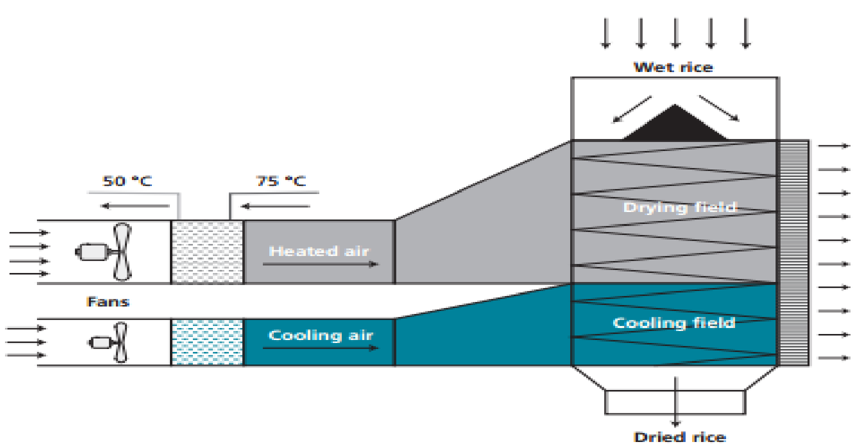


Figure 9 Convective Geothermal Rice Dryer (Van Nguyen, Arason, Gissurarson, & Palsson, 2015)

The only pilot geothermal drying in Kenya has been done in Eburru for drying of pyrethrum, tobacco and maize. The geothermal fruit dryer in Mexico was designed by Lund and Rangel in 1995. The drying chamber temperatures was kept at 60℃ to reduce the moisture content of fresh fruits from 80% to about 20% in 24 hours. The geothermal water flow rate is maintained at 0.03kg/s. It has been proposed that cascading can be used to increase the effeciency of the system thus reducing the cost of production. Indonesia has largely utilized their great geothermal potential in drying of most of their crops such as coffee, berries, tea, rice, beans and fish. They utilize geothermal steam direct from the well at the temperature of 160℃ which heats air for drying purposes at the heat exchanger. The air velocity is maintained in the range of 4 to 9m/s while the drying temperature ranges from 45℃ to 60℃. The drying time varies depending on the moisture content of the material being dried (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

Grain drying can easily be adopted in geothermal heat drying. A batch type deep bed dryer is commonly used dryer in grain drying. The fan component blows the air through the heat exchanger to be heated to the required drying temperature. Most of the grains dry at the air temperatures approximately 90℃, however, most dryers set the drying temperatures at 50-60℃ and relative humidity of about 40%. Drying of coffee for example, drying temperature ranges from 50℃ to 60℃ while for rice it must be maintained at 40℃ to avoid breaking. The equilibrium moisture content for most of the dried grains is between 12% to13percent. This hinders growth of moulds and spoilage due to wetness (Van Nguyen, Arason, Gissurarson, & Palsson, 2015).

3.6.3 Geothermal Drying System Components

The heat from the geothermal resource has to be harnessed then transferred to the drying unit to increase the temperature of the drying air which is then used to pick moisture from the product being dried.

The components discussed in the section below forms part of the geothermal drying system

3.6.3.1 Heat Exchangers (Direct and open loop system)

Heat exchangers are the heat carriers from the geothermal fluids to the working fluids without mixing. The selection depends on chemical composition of fluid, environmental considerations, economy among other factors.

Open loop or direct use of geothermal fluid is used in cases of low corrosion and scaling limit has not been attained. This ensures that the geothermal fluid leaving the heat exchanger has the temperature higher than the scaling limit temperature. In this case, the scaling limit temperature is 110℃. In case of more corrosive geothermal fluid, closed loop or indirect connection is preferred (Popovski & Popovska, 2010).

3.6.3.2 Types of Heat Exchangers

The most commonly used types of heat exchangers in geothermal systems includes: Plate heat exchangers, shell and tube heat exchangers and down hole heat exchangers

3.6.3.2.1 Plate heat exchangers

They consist of a series of plate with gaskets which are held together by clamping rods. The counter current flow is recommended in order to provide for high efficient heat exchange in small fluid volumes. They occupy less space compared to the shell and tube heat exchangers and can easily be expanded whenever the higher load is needed. In addition, it costs about 40% less than the shell and tube heat exchangers of the same capacity. The plates are to be made of stainless steel under low corrosion and titanium in high corrosive fluids (Popovski & Popovska, 2010).

Plate type heat exchanger was represented in figure 10 below

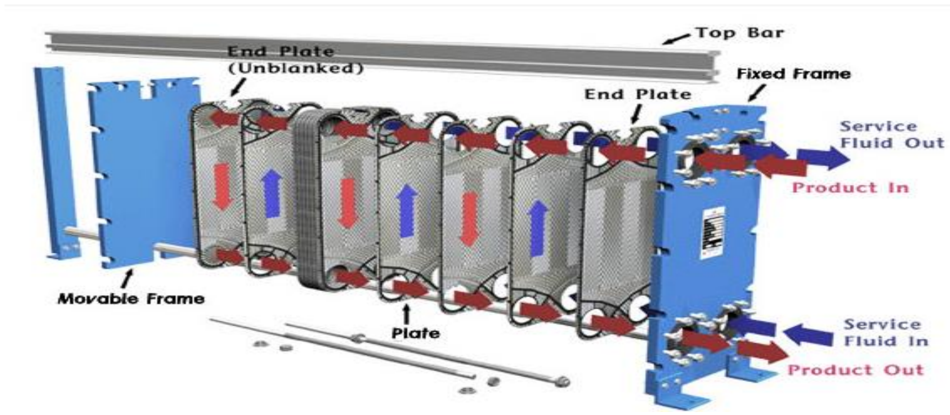


Figure 10 Plate type heat exchanger (Popovski & Popovska, 2010)

3.6.3.2.2 Shell and tube heat exchangers

These kinds of heat exchangers are less popular because of fouling, occupy larger space and require greater approach temperature (difference between the incoming and outgoing fluid temperatures). Figure (11) below represents the shell and tube heat exchanger.

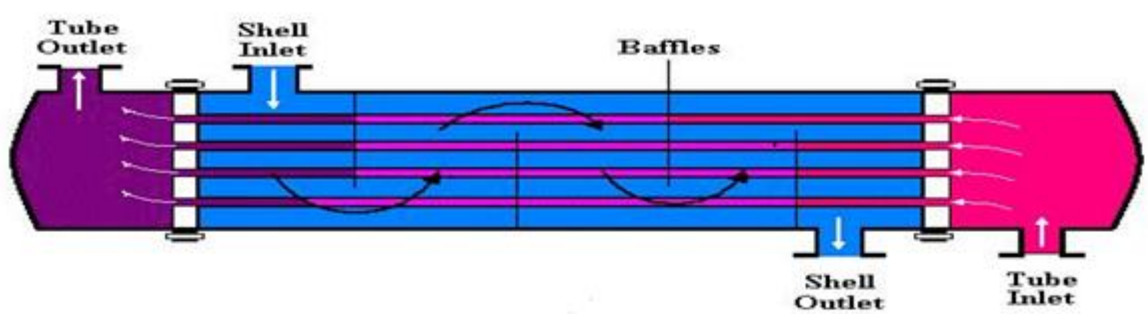


Figure 11 Shell and tube heat exchangers

2.7.3.2.3 Down hole heat exchangers

This kind of heat exchanger extract heat directly from the geothermal aquifer thus doesn't require well completion. They are mostly applicable in shallower geothermal heat sources. The heat exchangers of such kind are of small capacity. Therefore limits the application to the heating of smaller private residences.

Figure (12) below is a representation of a down-hole heat exchanger.

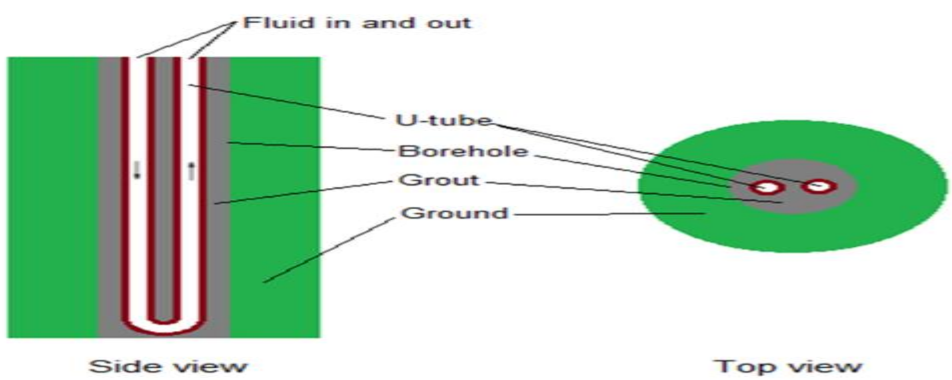


Figure 12 Down hole heat exchanger (Popovski & Popovska, 2010)

3.6.3.2.3 Heat Distribution and piping

In most cases, the geothermal resource is found in remote distant regions away from the main load center. This therefore requires transmission of this resource to the place of application. These resources can either be in liquid, steam vapor or two phase mixture form. The fluids are always in high temperatures varying from50℃ to 200℃ which may cause stress in the pipes thus careful engineering design is required (Popovski & Popovska, 2010).

Carbon steel has been widely used materials in the manufacture of geothermal distribution system pipes. Fitters are also made from carbon steel material. In case of underground transmission, the joints are welded. The use of steel pipes however have been limited due to the corrosion resulting from high chemical concentration of the geothermal fluid or if the fluid has been exposed to the air before entering the pipe (Popovski & Popovska, 2010).

Galvanized steel has been used in some occasions but yielded mixed success results. The zinc coating used in galvanization may not be effective in the temperatures above 60℃. Fiberglass piping also known as fiber glass reinforced plastics can be compounded and serviceable at the temperatures up to 140℃. However, much care is needed in order to maintain the operating pressure high enough to avoid flashing of high temperature fluids. PVC are applicable in low temperature fluids of maximum up to 60℃. They are second to carbon steel as the most commonly used materials in piping. CPVC can operating in higher temperatures rated up to 100℃. The handling of pressure ability is however very low. Polyethylene and other related materials can be used. However, their allowable operating temperature is very low, ranging from 40℃ to 50℃ (Popovski & Popovska, 2010).

The pipelines can either installed above the ground or underground connection. Above the ground pipe installations are supported on concrete slabs and rollers to allow for movement. This method of installation makes it easy to maintain the system. The main shortcomings for this system include; subject to vandalism and damage, constrains other physical development such as road constructions. The construction considerations should therefore include pipe supports and constraints, possible infrastructural crossings such as roads, provision of expansions, insulation protection and venting (Popovski & Popovska, 2010).

The underground installations are aesthetically attractive, not prone to accidents and intentional damage, stealing and vandalization. The main challenge in this type of installation is the external pipe corrosion, and not easily accessible for service connection and maintenance but more expensive. However, the life expectancy is high and the maintenance costs are the lowest.

4.0 TECHNICAL FEASIBILITY

4.1 Dryer Selection Criteria

In most cases, factors such as energy efficiency, grain quality rate and the initial cost have been considered in dryers selection. However, most recent researches have included factors such as lower horse power demand, low or minimal air pollution and the availability of the operating expertise as some of the key factors in selection of dryers.The selection guidelines based on world bank include: fixed cost per tonne capacity, reliability and manufacturers service record, dryer type, grain quality characteristics, specific energy consumption, expertise requirement for operation, air/noise pollution, dryers controls, maintenance costs and service life. According to the World Bank standards, initial cost of the dryer accounts to about 60% of the total selection score while 40% goes to the remaining selection factors (Maier & Bakker-Erkema,2002).

4.2 Mechanical Dryer Types

Mechanical dryers can be classified basing on the direction of flow of materials and the drying air air. The classifications based on these criterias include: cross flow, counter-flow, mixed flow and concurrent flow.

These drying categories based on the direction of flow has been represented in the figures (13).

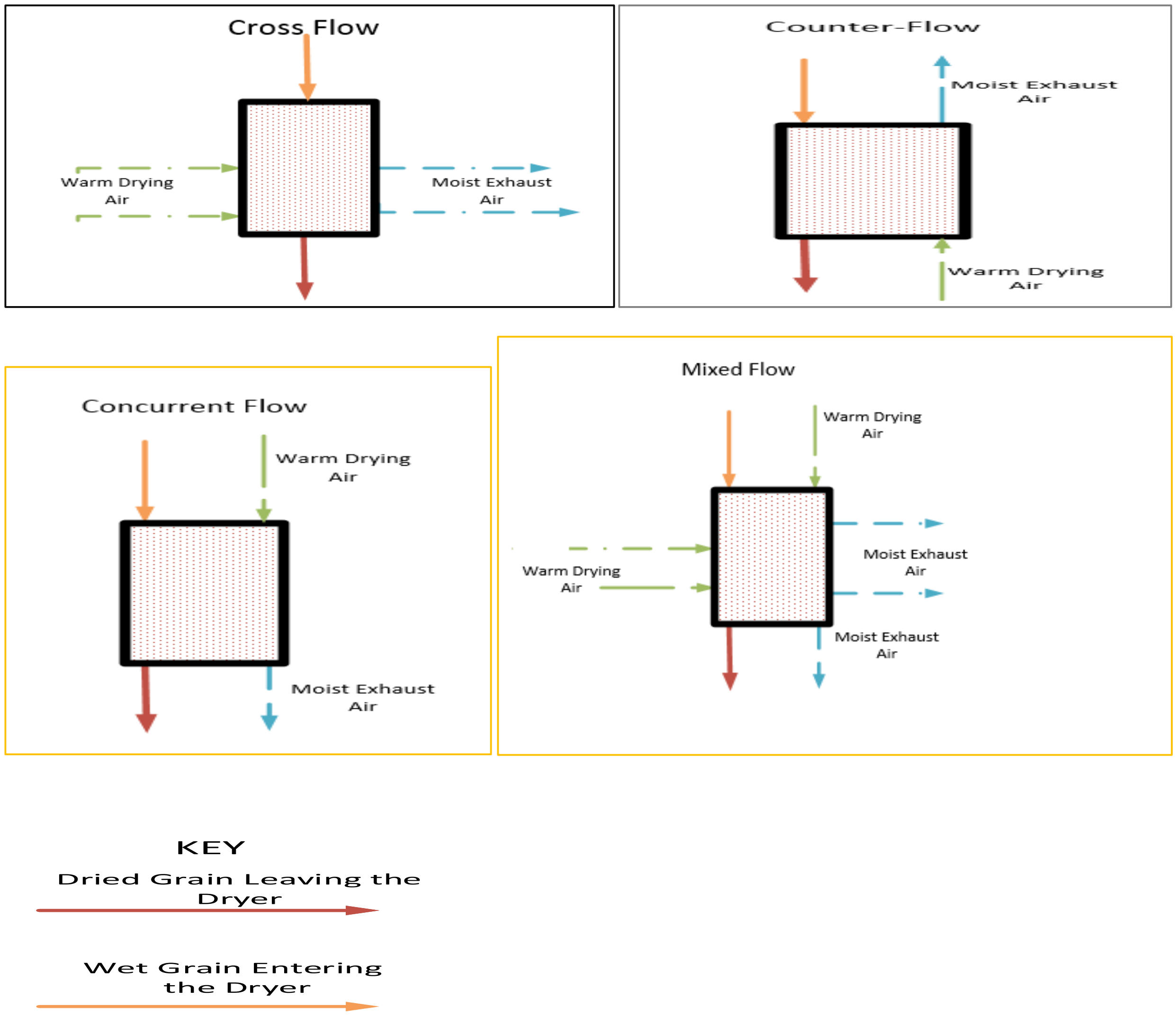


Figure 13 Drying Modes Basing on Direction of Flow (Maier & Bakker-Ekerma).

Cross flow dryers are characterized by the flow of drying air and the flow of the grains being dried moving perpendicular to one another. The drying air in these dryers can be set in the range 80-110°C with the maximum grain temperatures being set at 80-110°C. In concurrent flow dryers, grains and the drying air flow in the same direction thus reducing the drying effectiveness of the system. The counter-flow dryers are characterized by the flow of the materials and the drying air in the opposite direction thus increasing the effectiveness of the drying process. Mixed flow is a combination of the other three drying systems. It therefore enhances uniformity in drying process.

In order to maintain the drying process in the concurrent flow system, more air mass flow is needed at the higher temperatures thus making it comparatively more expensive (Maier & Bakker-Arkema, 2002).

4.3 Convective Grain Dryer Types

Shoedarto (2014) stated that convective mode heat transfer is the most preferable in drying of grains. The convective drying mode can take place in three basic ways according to Propovska and Vasilevska (1995): Drying with reheating air which occurs in multi-zone dryers on materials that are very thermo-sensitive and doesn't require the initial temperatures to be high, Drying with re-circulation of used air: in this method, the air leaving the dryer is partially exhausted, thus it is mixed with fresh air then recirculated back into the dryer and combination of reheating air and air recirculation mode: Mostly employed in multi zones driers designed for counter current flow.

4.3.1 Cabinet (Tray) Drier

This is a batch type multipurpose dryer operated by hot air. The main components of this type of dryer is the insulated cabinet, air heater, a fan and trays where drying materials can be placed. They are available in varying sizes i.e. from smaller units holding about two trays to large scale industrial sizes. The air can be blown to flow on the surface of the drying products or through the perforated trays holding these products. The exhausted air can be partially recirculated using dampers. (Shoedarto, 2014). (Brennan, 2006).

Figure (14) below is a representation of the cabinet dryer:

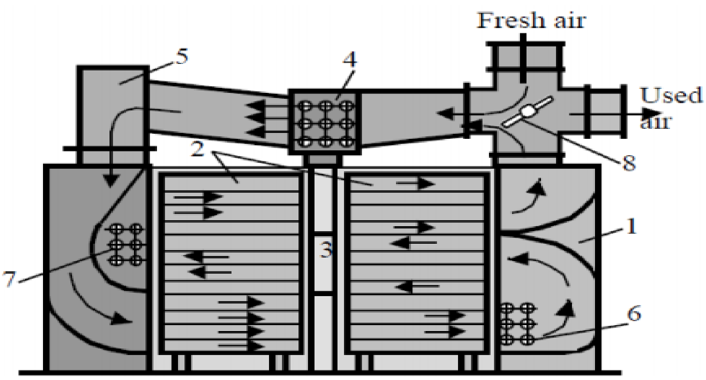


Figure 14 Cabinet Dryer Type. (Vasilevska, 1995)

1.Drying Chamber; 2. Wagon; 3. Partitions; 4,6,7. Heat Exchangers; 5. Fan; Flow requlating valve.

4.3.2 Tunnel Dryers

The major component of this type of dryer is an insulated tunnel through which the trolley carrying the materials to be dried enters. The flow of drying air and the materials being dried can be concurrent, counter flow and cross flow to one another. The movement of materials in this dryer is semi continuous because the trays are to be emptied at the exit and loaded at the entrance. This kind of dryer is best suited for drying of sliced fruits and vegetables. (Brennan, 2006).

The tunnel type dryer has been represented in figure (15) below

Figure 15 Tunnel Dryer (Ji nan keysong machinery Co.LTD, 2016)

4.3.3 Conveyor Dryers

The products are dried as they pass through the drying tunnel either on a perforated conveyor or hinged or perforated metal plate (Brennan, 2006). The drying air passes through the wet materials upwards in cross flow direction through the perforations. The conveyors can be 50m long and 2-3m wide. The capacity of this type of dryer is less than that of tunnel dryers occupying the same floor space. The use of multi stage conveyors is most common in most conveyors (Shoedarto, 2014). The multi stage conveyors are mostly used because they are said to be more efficiency than the single stage conveyor. The new side drying materials are exposed to heated drying air as they move from one stage to another thus achieving the uniformity in drying. In the operation, the drying air temperatures and velocity are always different from one stage to the other. Therefore, proper control of these parameters minimizes the damages caused by heat. These types of dryers are however relatively expensive and can only be used in rapid removal of moisture in initial drying stages thus requires an extra dryer to complete the drying process (Brennan, 2006).

Figure (16) below indicates the parts of the conveyor type dryer.

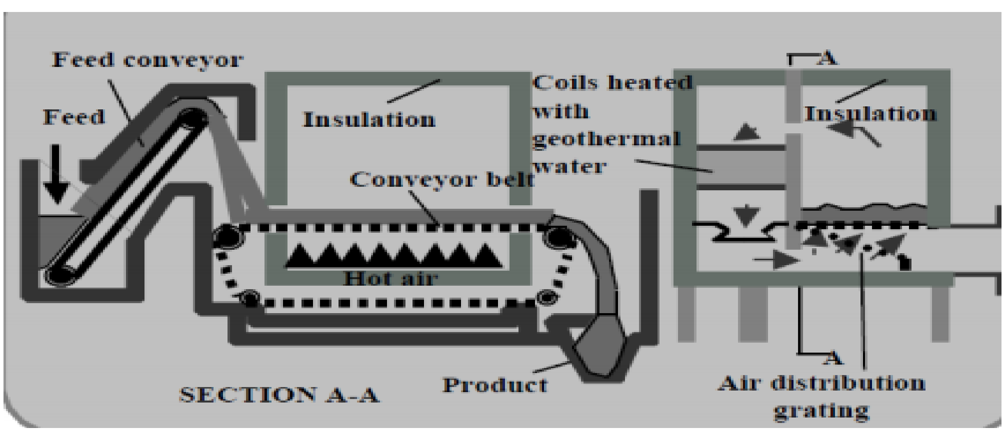


Figure 16: Conveyor Type Dryer (Popovski & Popovska, 2010)

4.3.4 Batch-In-Bin Dryers

These can be used both in on farm drying and commercial or industrial drying purposes. The on farm dryer type is known as the flat bed dryers with capacity of about 1 to 3 tons per day with approximate drying time of 6 to 12 hours. They can be made from brick, wood or metal on the surface with a perforated floor to allow easy air flow. The recommended length of the dryer is about 2 to 3 times its width. Flat bed dryers have relatively shallower grain depth of 0.4 to 0.7 m and the air velocity of 0.08 to 0.15m/s and 0.15 to 0.25m/s in maize and rice drying respectively to avoid the moisture build up. In tropical areas, drying of grains requires the temperature range of 40 to 45℃. The pressure drop is relatively low at 250-500 pa. In order to achieve the drying temperatures, both direct and indirect heaters can be used (FAO Agriculture and Consumer Protection, 2016).

Larger batch-in-dryers can also be used as stores thus saving on both capital and operational costs. They can handle grains in capacity of ten up to hundreds of tons. The grain depths range from 2 to 5m. The air distributing ducts are placed at the base of the dryers at a distance of half the depth of grain from each other and a quarter the depth from the end of the side wall as shown below

The recommended air velocity through the ducts should not exceed 5m/s to cater for the pressure drop.

Batch air bin dryer is represented in figure (17) below.

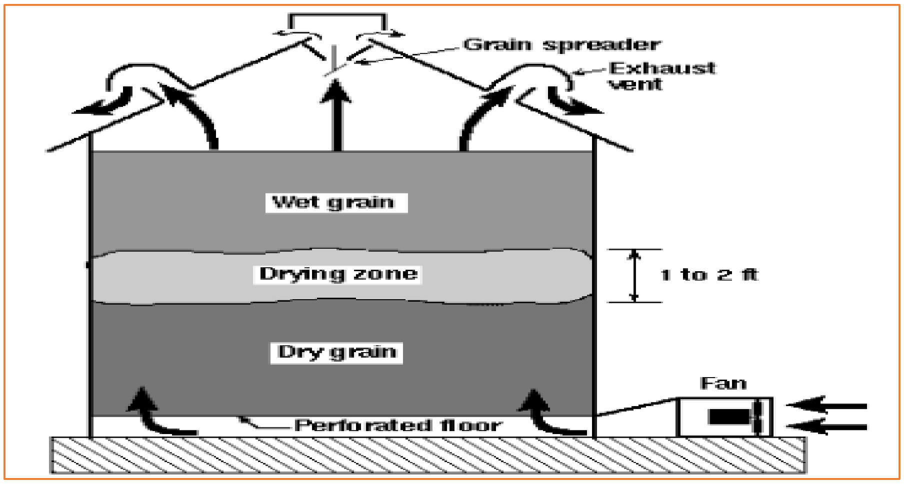


Figure 17 Natural Air Bin Dryer (William & Vance, 2009)

4.3.5 Fluidized Bed Dryer

This is through flow type of dryer operating at comparatively higher drying air velocities than in bin and conveyor dryers. The heated drying air is blown upwards through the perforated base of the dryer. The increased velocity of drying air increases the pressure drop across the bed. When the velocity of the drying air reaches a certain velocity known as the incipient velocity, the fractional drag acting on the surface of the particles exceeds the particle weight (Brennan, 2006). This condition expands the bed and suspends the particles in the air thus making them behave like liquids as circulate within the bed. This state gives them the name fluidized bed.

The fluidized bed dryers can either operate as batch or continuous mode. However, batch operations are mostly preferred in small scale. Uniform mixing in batch operations results in uniform moisture content after drying. Food industries prefer the use of continuous mode. In this mode however, the density and the moisture content of the final products depend on the density and moisture content of the feed products respectively i.e. the mixing is not uniform.

The horizontal multiple chamber continuous fluidized dryer was represented in figure (18) below

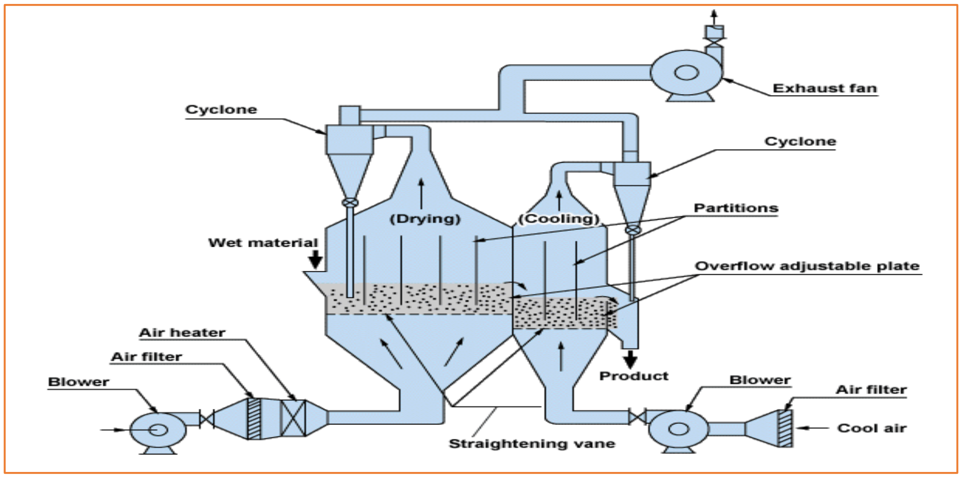


Figure 18 Continuous Fluidized Dryer (Kurimoto LTD., 2016)

4.3.6 Pneumatic Dryers

These dryers are characterized by chambers or tubes in which products are dried while they are being transported pneumatically. The design is set that drying air velocity is higher than the velocity of the particles i.e. the air velocity is about 10 to 20% more than the levitation velocity of the largest particle. The particle velocities range from 10 to 40m/s depending on their dimensions. In addition to drying energy, electricity consumption is also needed to move the particles. These dryers can be applied in drying of vegetable leaves, dairy food and grains. The duration of the materials passing through the tube don't exceed 1 to 2 seconds this makes it possible only to evaporate the superficial moisture only in most scenarios. (Shoedarto, 2014).

The important parts of a pneumatic dryer are shown in figure (19) below.

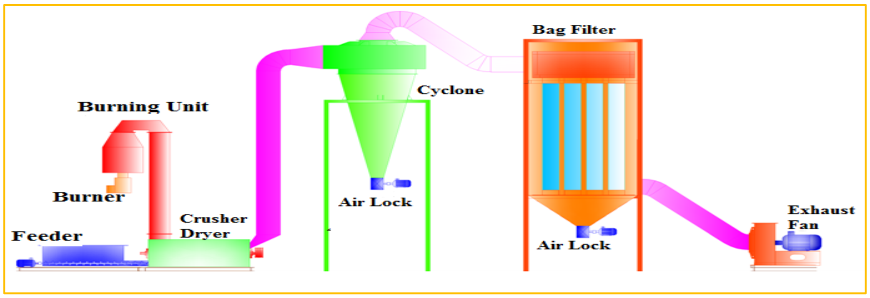


Figure 19 Pneumatic Dryer (EKSIS, 2007)

4.4 Batch and Continous Drying

Batch drying is characterized by the drying system with a set volume of grain being dried at a given time. This volume is dependent on the holding capacity of the dryer and the amount of moisture content to be removed from the grain mass. The loading of the next batch of the grains to be dried is only to be done after the first batch of the grains have attained the recommended moisture content. Therefore, loading and unloading time in batch drying should be considered.

Batch drying systems can either be static or mixing system. The static system can either be thin layer bed, thick layer bed, and vertical thin layer batch or round structure radial dryers. The main disadvantage in static systems is over drying of the grains that are nearest to the incoming heated air as they lose the moisture first as the hot air temperature drops for absorbing the moisture from the first grains. This reduces the capacity of air to dry as it passes through the grain bed layer. The mixing system is therefore put in place to overcome the problems in the static system. The dryers therefore are usually designed as a tall vertical column to ease mixing during drying. It is recommended that the grains to be rotated 3-4 times before the drying process is complete (Maitri & Viboon, N.A).

In continuous drying system, the grains are always passing through the dryer without stopping to load and unload. The features in this system are more like that of the mixing static batch dryers. In order to achieve efficient drying, the operator of continuous dryers should possess high knowledge in grain drying management in order to precisely program the drying process. This system is relatively cheaper, drying uniformity and higher drying capacity compared to the mixing batch dryer under the same conditions. The grains have to be held in buffer bins for about 6 hours or more to equalize the moisture content within the kernel. The grains passing through the dryer for the first time reduces 2 to 4% of the initial moisture content. Therefore, the grains are to be stored in a buffer bin before being recycled into the dryer till the equilibrium moisture content is achieved. (Maitri & Viboon, N.A)

5.0 CROPS PRODUCTION IN KENYA

Kenya grows a variety of food crops across the country. These crops are grown depending on the climatic conditions of different regions in the country. These food crops in order of importance in the country include: Maize, Beans, Irish potatoes, Wheat, Rice, Cassava, Sorghum and Millet (GDC & USAID, 2013). About 75% of the Kenya's stable food and vegetables is supplied by small scale farmers Unreliable weather conditions and volatile market conditions are some of the major challenges facing these farmers. Kenya imports approximately 10% and 90% of maize and wheat respectively to curb for the shortages due to deterioration during storage and other causes (Ministry of Agriculture, 2013).

All the food and cash crops grown in Kenya are always in surplus at harvesting time but scarce in other seasons of the year. Therefore, storage is preferred in order to overcome the unreliable climatic conditions and also to feature high prices with time. Drying of these agricultural products increases the longevity of drying. Use of geothermal heat for achieving these drying needs can be environmentally viable. The quantity of each of these crops produced in Kenya is extensively discussed in the section below:

5.1 Food Crops

5.1.1 Maize

Maize is the main staple food for the country thus its production have a direct impact on the food security in the country. The average maize production in country has remained fairly average since 2010. It is mostly produced in the rift valley and the western regions in Kenya. According to (GDC & USAID, 2013) report, the great rift valley region accounts for about 80% while Western and Nyanza accounts for 14% each of the total energy produced yearly in Kenya. Maize crop is the most relied upon staple food in the country. It can either be milled or eaten in green form or mixed with other grains in dried form to be boiled (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 9 Maize production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Dry maize(Tons)	3,464,541	3,376,862	3,749,880	3,592,688	3,513,171

5.1.2 Wheat

The country registered a decrease in wheat production by 23% in 2014 because of the poor rainfall experienced in the growing regions that year. Narok County accounts to about 45% of the total wheat production in the country. The ministry of agriculture, livestock and fisheries has recorded that the demand for wheat has been increasing in the last five years thus importing to meet the demands (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 10 Wheat Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Wheat (Tons)	511,994	268,482	441,499	449,641	328,637

5.1.3 Barley

It is normally grown on contractual basis between the beer companies and individual farmers. There was an increase of 13% in production from 2013 to 2014. The increase in production was attributed to an increased demand thus increase in area under crop production (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 11 Barley Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Barley (Tons)	64,219	65,235	72,426	57,671	65,402

5.1.4 Rice

Rice in Kenya is mostly grown in national irrigation schemes. There was a decline in production from 2013 to 2014. The decline was attributed to insufficient rainfall and reduced water in the irrigation schemes (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 12 Rice Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Rice (Tons)	110,494	111,229	138,204	125,256	112,263

5.1.5 Sorghum

The production of sorghum has greatly increased from 2012 to 2014 mostly in ASAL regions. The increase has been attributed to government's effort to revive production of drought resistant crops such as sorghum and increased demand from the beer making industry. The production is highest in Nyanza and Eastern regions accounting for 72% of the total production (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 13 Sorghum Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Sorghum (Tons)	110,494	111,229	166,627	168,857	177,553

5.1.6 Millet

There has been an increased awareness to adoption of drought resistant crops. This has led to an increase in millet production in the last five years. The increased production of this crop have been have been registered in marginalized areas of Nyanza and Eastern regions (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 14 Millet Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Years	2010	2011	2012	2013	2014
Millet (Tons)	110,494	111,229	138,204	125,256	1,442,761

5.1.7 Beans

The production has declined from 2013 to 2014. This was attributed to reduction of land under beans cultivation and unfavorable weather conditions (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 15 Beans Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Beans (Tons)	390,598	577,674	622,759	714,492	616,992

5.2 Industrial crops

5.2.1 Coffee

There was a rapid reduction in production of coffee in 2012 compared to 2011 production. The areas under coffee production marginally increased from 2013 to 2014 as a result of better management both in production and cooperative levels. The larger percentage of the produced coffee is exported (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 16 Coffee Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Coffee(Ton)	42,000	36,260	49,000	39,800	51,500

5.2.2 Tea

The area under production and the quantity of production in tea increased by about 2.2% and 2.9% respectively in 2014. The estate subsectors as well as the smaller holder sectors have also registered marginal increase in production. Most of the tea produced is exported. Kericho, Bomet and Nandi counties are the highest producers of tea in the country (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 17 Tea Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Tea (Tons)	399,006	377,912	369,400	432,453	445,105

5.2.3 Cotton

Cotton production in Kenya declined by 53% in 2012 compared to 2011. However, the production has since increased from 2012 to 2014. The increase has been attributed to the improved management practices employed by cotton farmers (Ministry of Agriculture, Livestock and Fisheries, 2015).

Table 18 Cotton Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Cotton (Tons)	11,822	22,104	11,772	12,873	13,472

5.2.4 Pyrethrum

The area under production has increased in 2014 compared to that in 2013. However, the amount of pyrethrum delivered to Pyrethrum Board has significantly decreased during the same period. Because of illegal trade and hoarding of pyrethrum. The earnings from the crop have increased from 2013 to 2014 (Ministry of Agriculture, Livestock and Fisheries, 2015).S

Table 19 Pyrethrum Production in Kenya (Ministry of Agriculture, Livestock and Fisheries, 2015)

Year	2010	2011	2012	2013	2014
Pyrethrum (Tons)	462	518	420	399.22	358.33

5.3 Crop Production Comparison

Different crops in Kenya are grown in different regions depending on the soil and climatic characteristics that favor them. The map of Kenya in figure 20 below represents the distribution of the major crops grown in Kenya.

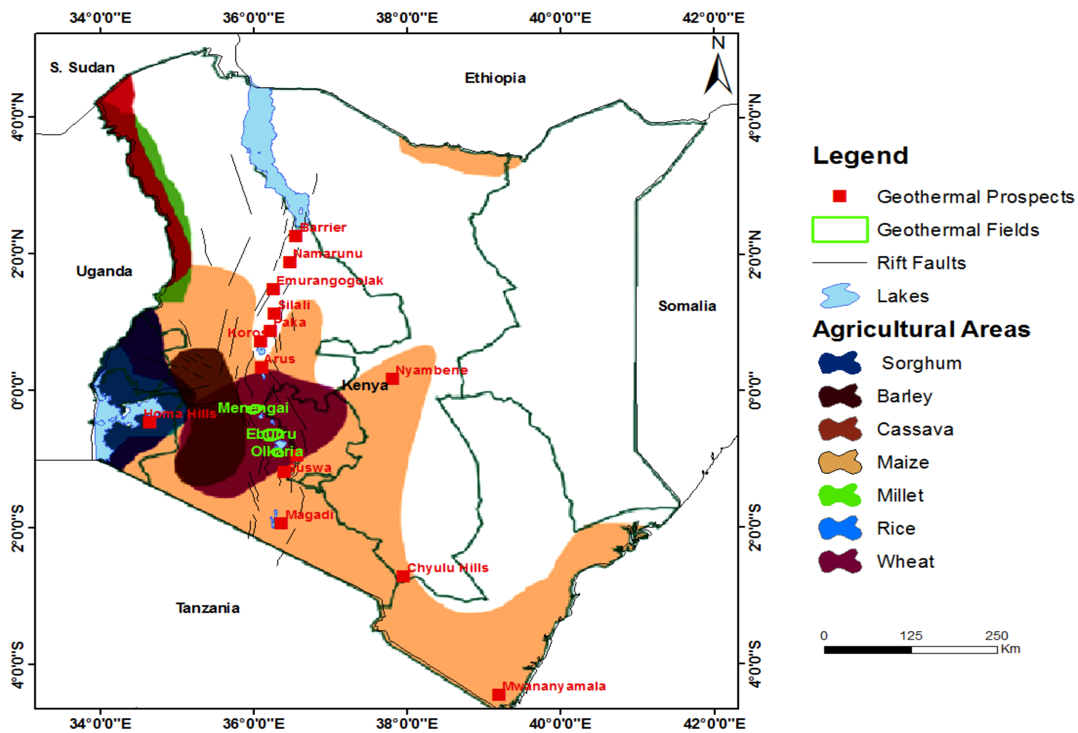


Figure 20 Distribution of major crops and Geothermal Resources Distribution in Kenya (GDC & USAID, 2013) (Kiplagat, Wanga, & Li, 2011)

The production of different major crops were compared over the years from 2010 to 2014. The line graphs were drawn to show the trends in this production as shown on the graph in figure 21 below:

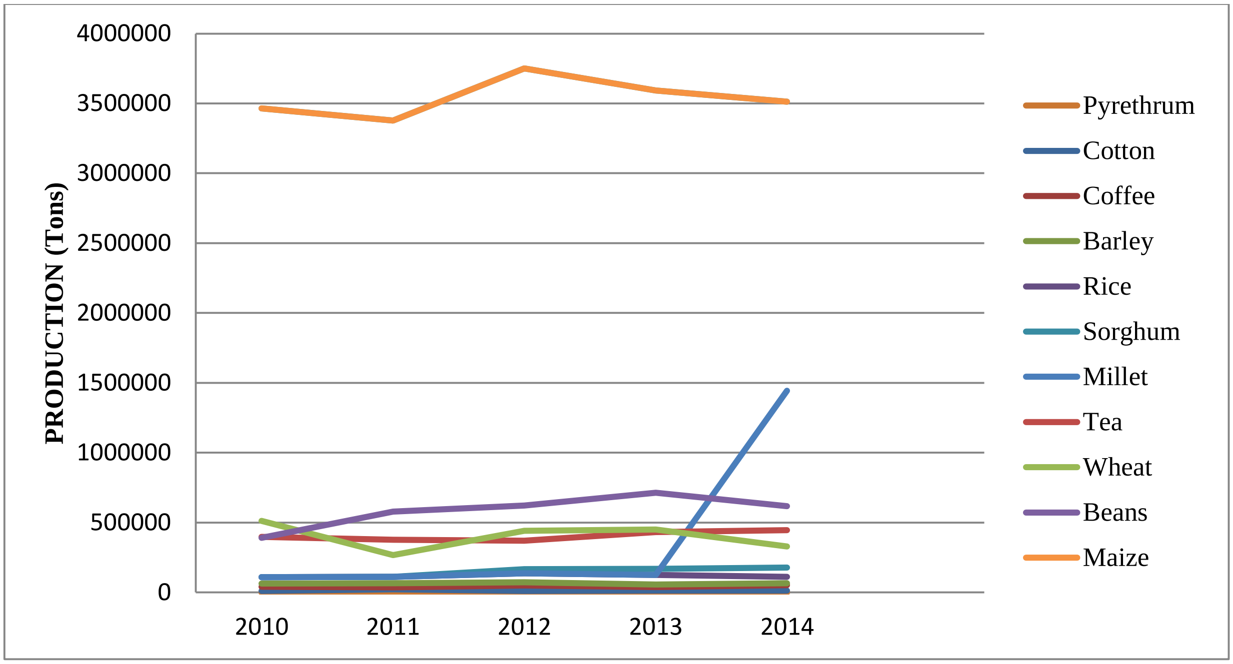


Figure 21Trend of Main Crop Production in Kenya (Ministry of Agriculture, 2013)

From the graph, it was noted that maize crop production was highest among all the major crops in Kenya followed by other cereal crops.

5.5 Maize production in Counties

Maize crop was considered for study in this project because the trend on the graph above showed that it has the highest production averagely.

The quantity of maize production in different counties in Kenya was compared and represented on the graph in figure 22 below.

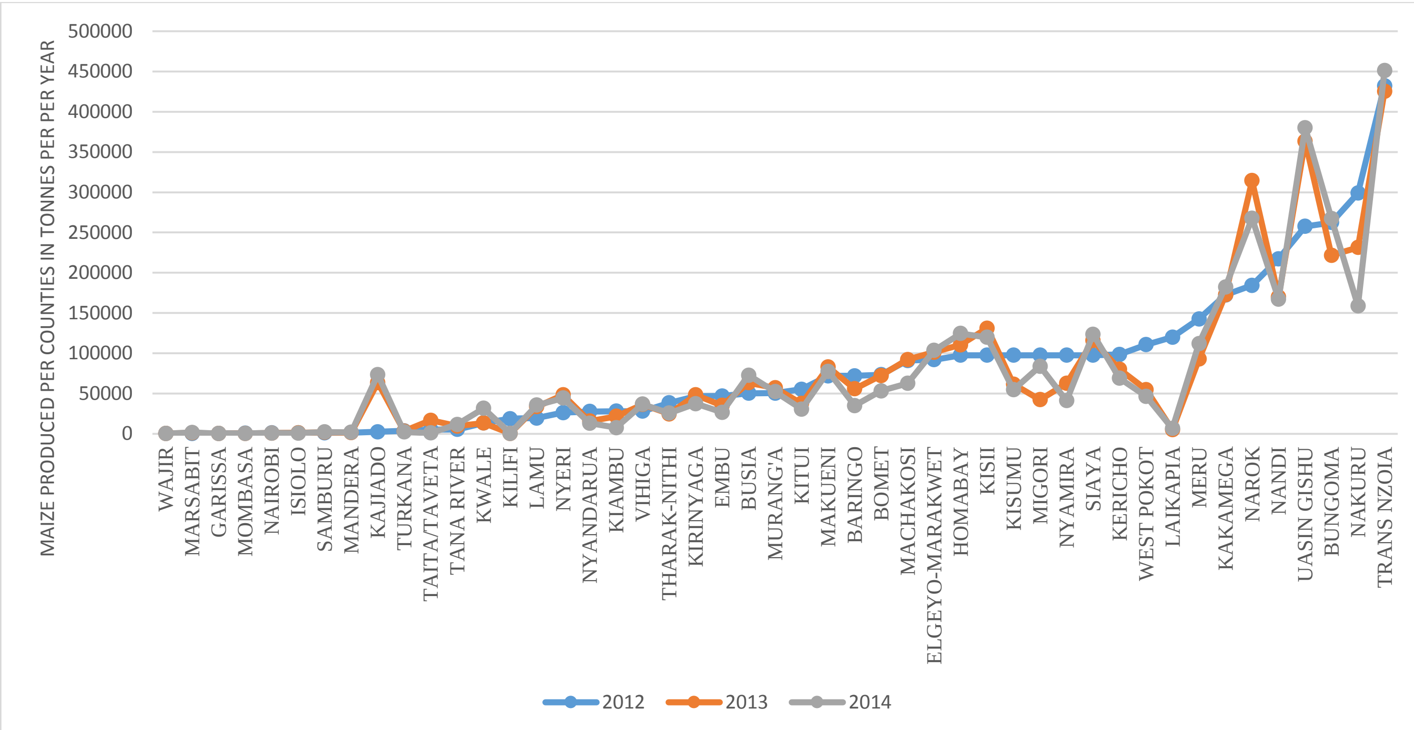


Figure 22 Maize Production per county since 2012 to 2014 (Ministry of Agriculture, 2013)

Maize farming in Kenya is typically dependent on rainfall seasons. The rain seasons are either short rain season or long rain season. The maize growing regions receive relatively enough rainfall that can support maize farming even in short rain seasons. The farmers grow early maturing maize varieties during short rain seasons. The harvesting season ranges from august to January each season. Different regions in the country harvest maize at different times of the year.

Assuming that each county harvests equal amount of maize per month in each harvesting season. The amount harvested per month per county was found by dividing the total amount harvested in the county then divide by the number of months per harvesting season. The amount of maize available for drying per month was found as the sum total of the maize produced per county per month. The average amount of maize produced per month in Kenya basing on 2012 to 2014 data was found and represented on the graph below:

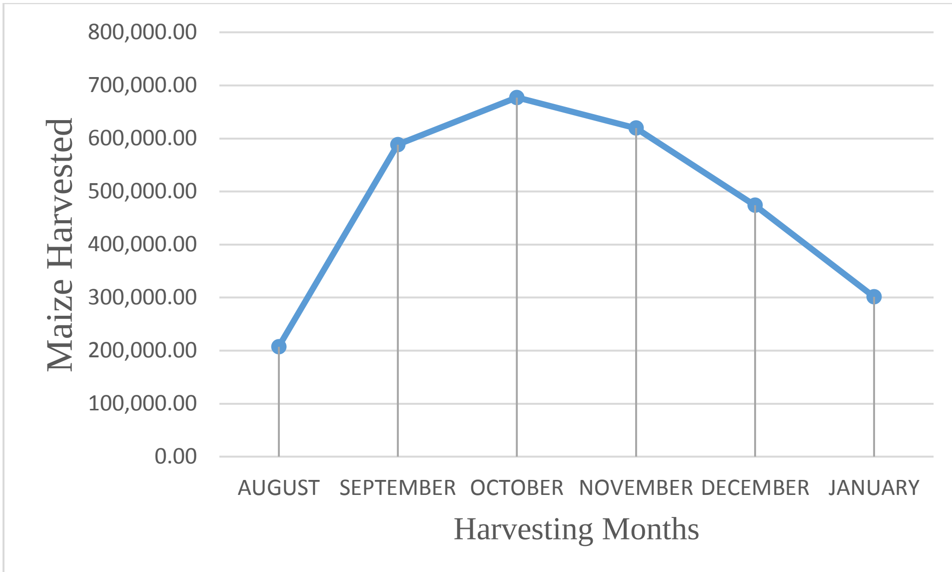


Figure 23 Maize Harvesting per Month per Season

From the graph above, the month of October recorded the highest amount of maize needed for drying while the august registered the least amount averagely.

6.0 GEOTHERMAL RESOURCES ASSESSMENT IN KENYA

Geothermal Energy exploration in Kenya started in 1960s. Two wells were drilled at Olkaria but geo-survey continued in 1970s, to identify more geothermal prospects by 1973 between Olkaria and Lake Bogoria. The government of Kenya through the ministry of Energy and Petroleum, Geothermal Development Corporation and KenGen have intensified geo-surveys and researches to identify more geothermal potential fields. The fields and prospects so far identified and recorded include: Suswa, Eburru, Menengai, Paka, L. Baringo, Korosi, Arusi-Bogoria and Longonot. More studies are still being done in areas such as Silali, L. Magadi, Badlands, Emuruangogolak, Barrier and Namarunu to establish their potential (Omenda, Silas, & Muchemi, 2014). These fields and prospects can be considered as the source of geothermal heat in agricultural drying.

The main geothermal fields and prospects in Kenya are shown on the map in figure 24:

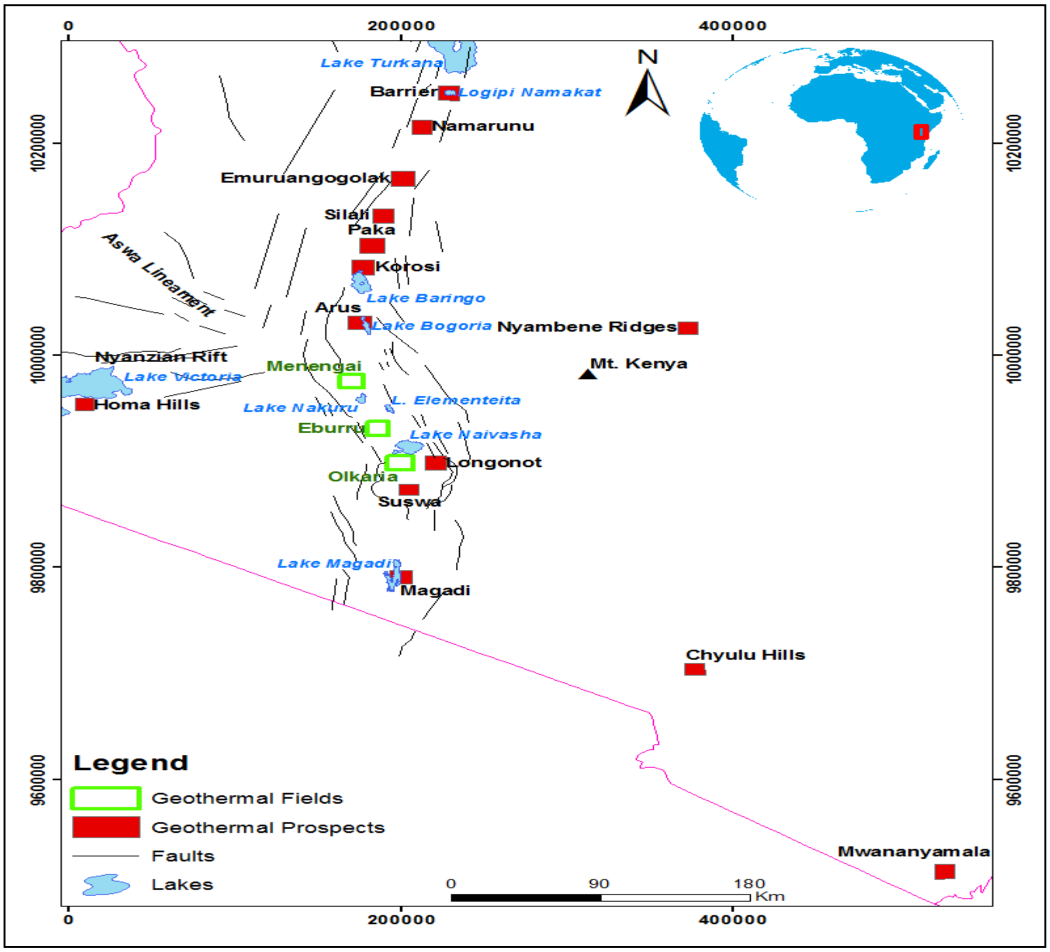


Figure 24 Geological Locations for Geothermal Fields and Prospects in Kenya (Omenda, Silas, & Muchemi, 2014)

According to Mariita (2010), geothermal energy utilization projects in Kenya are mostly in Olkaria regions. Olkaria geothermal field has been sub divided into seven sectors namely: Olkaria Northeast field, Olkaria East, Olkaria West, Olkaria Central, Olkaria South West, Olkaria Northwest and Olkaria domes regions. The geothermal resource is currently being utilized for power generation about 573MWe and direct use of 22.4MWt. Most of the utilization projects in this region are mostly for electricity generation. However, more research is being undertaken to establish the feasibility of other forms of utilization including use geothermal heat for agricultural products drying.

The section below discusses different geothermal fields and prospects in Kenya

6.1 Olkaria Geothermal Fields

These Geothermal fields are found on the floor of Kenyan rift valley. Geothermal resource occurrence was due to rifting and faulting of the continental tectonic plates causing volcanic activities. The main source of heat is believed to be from the magma intrusions found in depth ranges of 5km to 8km. The reservoir in this field is dominated with the liquid with average temperatures 230℃ to 260℃. The chemistry characteristics of the fluids have shown that it is highly alkaline due to chlorine waters. Total dissolved solids (TDS) and Bicarbonate contents are very low (Kwambai, 2005).

Olkaria (I) power plant owned by Kenya Electricity Generating Company (KENGEN). The field is located in Olkaria east region and has three generating units each of 15MWe giving a total of 45MWe. The region has 33 drilled wells of which only 26 wells are productive while the rest have declined with time thus becoming noncommercial producers. In 2014, the Olkaria (I) fields were expanded by adding two wellhead generators of capacity 70MWe.each. The steam production was increased by drilling the wells deeper to 3000m from previous depth of 900m to 2200m. Olkaria. (II) Power plant in North East region is a 2× 35MWe. This plant is said to be relatively more efficient compared to Olkaria (I) with specific steam consumption of about 7.2t/hr per MWe. The high efficiency plants let to surplus steam in the field thus KENGEN has proposed an additional unit of 35MWe increasing the capacity to about 105MWe. Olkaria (III) power plant is located in Olkaria West field. The power plant is operated and owned by Ormat International which is the first and currently the only privately operated geothermal power plant. The installed capacity of Olkaria (III) is currently at 110MWe. It operates on Organic Rankine Cycle (ORC) Binary plants turbines (Omenda, Silas, & Muchemi, 2014).

Olkaria (IV) field also known as Olkaria domes field found in the eastern part of the region. The field has a capacity of 350MWe but only two power plants rated 70MWe each has been completed and commissioned. The remaining parts of the field are still under appraisal and production drilling. These regions are being anticipated to host 140MWe Olkaria (VI) power plant. Olkaria Central Fields (Oserian Plants) the field is located between Olkaria West and North East fields. The wells in this field were drilled in lower reservoir temperatures and lower permeability resulting in the low outputs. Oserian Development Company (ODC) leased wells OW-306 and OW-202 from KenGen and they constructed two 2MWe power plants running on Organic Rankine Cycle and back pressures technologies. ODC is also using steam well OW-101 for direct us in heating of green houses and sterilizing of soils.

6.2 Eburru Geothermal Field

The field is located in the north of Olkaria Geothermal field. The capacity of Eburru geothermal field is said to be about 60MWe. However, only 2.5MWe condensing pilot plant has been constructed and operational. The upper reservoir has shown the low temperature hydrothermal minerals implying the temperatures between 150℃ to 180℃ However, the main reservoirs have higher temperatures ranging from 250℃ to 320℃ (Mwarania, 2014). The field is liquid dominated.

Table 20 Temperatures at Eburru Geothermal Fields (Mwarania, 2014)

Well	EW-01	EW-02	EW-03	EW-04	EW-05	EW-06
Max Temp ℃	278.9	140.1	167.8	193.2	165.5	219.9

From table 20 above, medium to low temperature wells of temperatures below 200℃ can be considered for agricultural products drying project. These wells are EW-02, EW-03, EW-04 and EW-05.The reinjection temperatures in this field was said to be around 40℃ (Mwarania, 2014)

6.3 Menengai Geothermal field

This field is located in a Quaternary caldera volcano which is within the axis of the Kenyan rift valley. The MT surveys showed that the field has a resistivity distribution of about 2000mb.s.l and the conductivity of less than 5ohm-m. The seismic wave attenuation at <6km according to seismology study indicated that there are shallow magma bodies that can be heat sources for Geothermal systems. According to the Gas Geothermometry based on H_2S and CO_2 showed that the reservoir temperatures are greater than 250℃. Since 2011, 25 wells with depths varying from 2,100 m to 3000m have been drilled. Several wells have encountered up to 400℃ at 2000m thus making it the hottest field in Kenya. The full steam production is expected for a planned 105MWe power plant.

6.4 Suswa Geothermal field.

This field is one of the series of Quaternary calderas found in the rift valley in Kenya. Suswa is found in the Southern most part. The volcanoes in this area comprises of phonolites, trachytes and other pyroclastic equivalents. Gas geochemistry studies done in this region indicates that the reservoir temperatures are >300℃. The gravity and seismic studies suggested that the heat source is at the depth of about 6km. Drilling exploitation on this area started in the year 2015 by GDC in conjunction with the private partners (Omenda, Silas, & Muchemi, 2014).

6.5 Longonot Prospect

Longonot area is one of the largest caldera volcanoes in the Kenyan rift with the diameter of 11km. The geothermal manifestations in the site are in form of fumaroles and hot grounds. The geochemical study already done indicates high CO_2 and radon presence. The reservoirs reveals that the temperatures are >300℃. Seismic and MT surveys have shown that the heat source can be found at the depth of 6km. Exploitation and drilling was expected to start in 2015 targeting to construct a 70MWe power plant by 2018 by African Rift Geothermal Limited (AGIL) (Kenneth, Alexander, & Ussher, 2011)

6.6 Baringo Prospect

The geothermal potential in this field has already been manifested in form of ground water boreholes, hot springs, fumaroles and thermally altered hot grounds. The gas Geothermometry surveys indicates that the reservoir temperatures ranging from 120℃ to 200℃. Resistivity study revealed the occurrence of fault lines in the region (Mungania et al., 2004). The drilling was expected to commence in 2015 by GDC.

6.7 Korosi prospect

This field is one of the caldera volcanoes found in Kenyan rift valley. The Geothermometry surveys have indicated that the reservoirs temperatures are >250℃. The exploitation and drilling was said to start in 2015 by GDC (Omenda, Silas, & Muchemi, 2014).

6.8 Paka Prospect

The manifestation was in form of fumaroles at the temperatures of >97℃. The surveys on the fluids in the reservoirs indicate that the systems temperatures are more than 250℃. Seismic surveys have indicated that the heat sources are as shallow as 5km below the surface. Exploitation and drilling was expected to be done by GDC as from 2015.

Other geothermal field prospects worth mentioning include L. Magadi, Emuruangogolak, and Namarunu and Barrier volcanic complex. These are all found in the Kenyan rift valley. The studies on these areas are being done by GDC from 2014 to around 2015 (Omenda, Silas, & Muchemi, 2014).

7.0 GEOTHERMAL ENERGY CLASSIFICATION AND UTILIZATION

7.1 Geothermal Resource Classification

Geothermal energy systems are mostly classified basing on the temperature of the system. These can either be low temperature or high temperature geothermal systems. In many written work, most of the authors classify geothermal resources as low temperature, medium temperature and high temperature geothermal resources (Mwagomba, 2016).Low temperature geothermal resources are those having temperatures below 150℃ and drilled to a depth below 1km. High temperature geothermal resources are drilled at depth above 1km and has temperatures of 200℃ and above. Any resource with temperatures in the range of 150℃ to 200℃ can be classified as medium temperature resources (Mburu, 2009).

Table 21 Geothermal Classification Based on Temperature (Mwagomba, 2016)

Low temperature systems	Medium temperature	High temperature
Reservoir temperature below 150 ℃ at 1km depth	Reservoir temperature between 150℃ to 200℃ at 1km depth	Reservoir temperatures high than 200℃ at 1km depth
Reservoir enthalpy less than 800kJ/kg	Reservoir enthalpy less than 800kJ/kg.	High reservoir enthalpy above 800kJ/kg
Liquid dominated fluid	Two phase fluid. Both steam and water	Vapour dominated reservoir

Geothermal energy resource can also be classified basing on the geological setting of the geothermal field. Geothermal resources in this category can either be volcanic, convective fracture controlled, hot dry rock or engineered/enhanced geothermal systems, sedimentary geo-pressured and shallow resources. Volcanic geothermal systems are very common in Kenyan rift valley. This is the geothermal resource whose heat is extracted from the volcanic magma. They occur in fissures along the tectonic plate boundaries or other hot areas associated with volcanic activities (Mwagomba, 2016).

Geothermal resource utilization is greatly influenced by the reservoir fluid temperatures and enthalpy rates. The utilization can be classified broadly as electricity generation, direct use application and other applications. Electricity generation utilizes geothermal resources with temperatures above 120℃ using steam flash or binary technologies which expands in the turbine to runs the generator to generate the electricity. Direct use application is the use of the geothermal heat without converting it into electricity (Mburu, 2009). The heat is extracted from the steam dominated hydro-geothermal resource by heat exchanger to be used in other non-power producing applications. The direct use application is mostly related to low temperature geothermal resources (<150℃) (Popovski & Popovska, 2010). These applications may include district heating, green house heating, aquaculture, bathing and spa.

The Lindal diagram indicating the utilization of geothermal fluids at different temperatures is shown in figure 25 below:

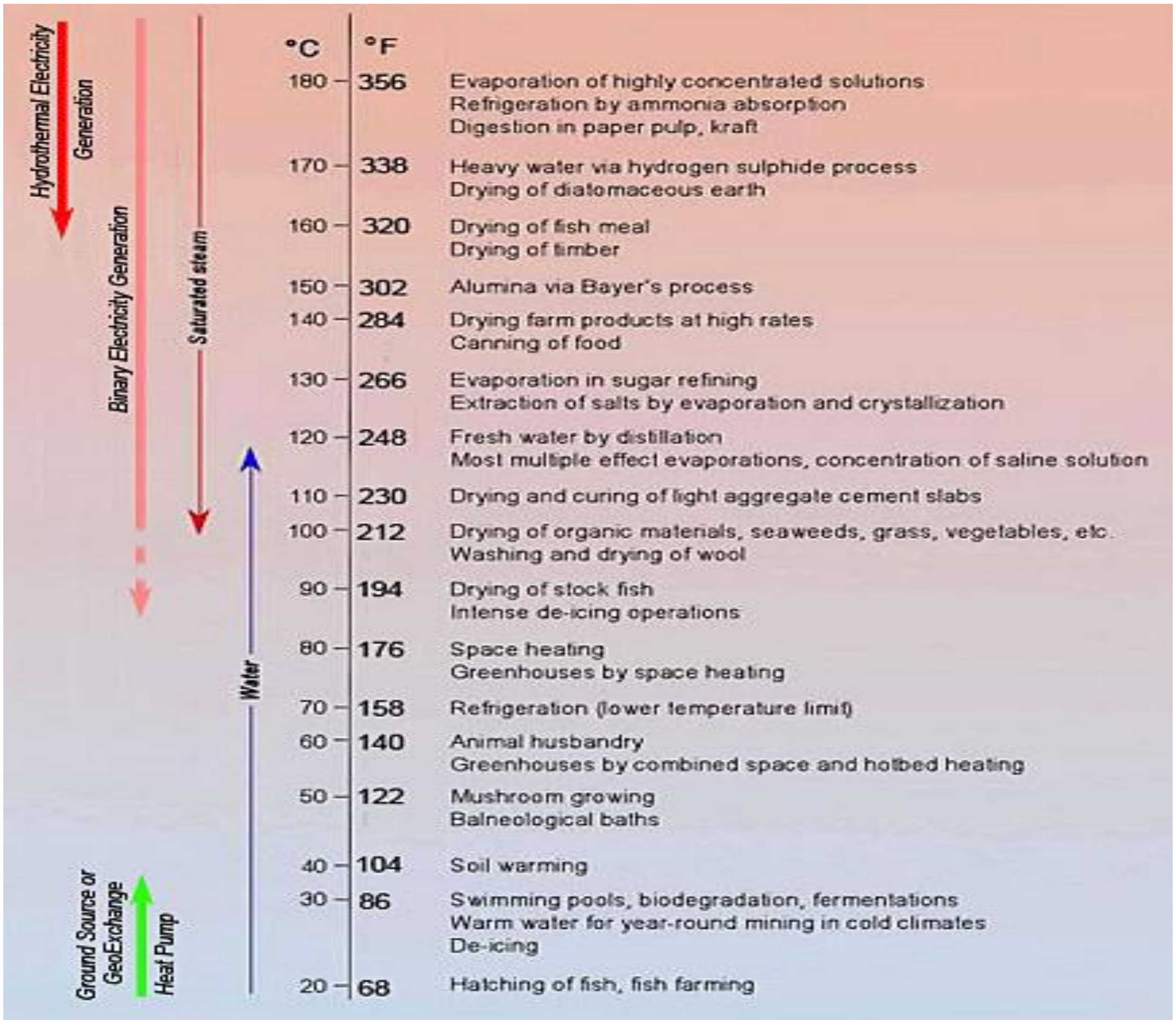


Figure 25 Lindal Diagram (Popovski & Popovska, 2010)

As indicated on the Lindal diagram above, drying of agricultural products can be done from temperature range of 90°C to about 180°C. Geothermal resource assessment section above indicated that majority of the geothermal fields and prospects in Kenya have temperatures within this range. Application geothermal heat for drying of agricultural can be feasible according to resource availability.

7.2 Geothermal Resources Application

Electricity production	Wells drilled into a geothermal reservoir produce hot water and steam from depths of up to 3 km. The geothermal energy is converted at a power plant into electric energy, or electricity. Hot water and steam are the carriers of the geothermal energy.
Direct use	Applications that use hot water from geothermal resources directly. Examples: space heating, crop & lumber drying, food preparation, aquaculture, industrial processes, etc. Historical traces back to ancient Roman times, e.g. for baths
Geothermal heat pumps	Taking advantage of relatively constant earth temperature as the source and sink of heat for both heating and cooling, as well as hot water provision. One of the most efficient heating and cooling systems available.
Hot Dry Rock Deep geothermal/EGS (both not commercial yet)	Extracts heat by creating a subsurface fracture system to which water can be added through injection wells. Water is heated by contact with the rock and returns to the surface through production wells. Energy is then converted at a power plant into electric energy as in a hydrothermal geothermal system.

Table 22 Geothermal Energy Application (Mburu, 2009)

High temperature geothermal reservoirs produce steam and/ or water which is then piped to power plants to run the turbines to generate electricity. In case of the mixture of steam and water, the steam is separated from water at the pressure. More research has shown that a combination of flash and binary cycle technologies have gained popularity in recent years due to its ability to utilize more heat from the resource (Mburu, 2009).

7.3 Direct Use Applications in Kenya

Mariita (2010) stated that almost 90% of geothermal utilization in Kenya is for electricity generation. However, more studies on direct use applications are being done to establish their viability. Residents had been using natural hot springs and fumaroles as places of worship and offering sacrifices especially when afflicted with ailments. The most recent direct use applications have been use of geothermal heat in drying of pyrethrum flowers while condensate used as drinking water in Eburru village. Greenhouse heating and bathing are other direct use applications adopted in Kenya. The section below discusses some of the geothermal direct use applications in Kenya

7.3.1 Greenhouse heating (Oserian Farm)

Oserian Development Company Limited is a privately owned flower farming and export company that leased a geothermal well from Kengen. The company is using geothermal energy resource in heating about 50 hectares of greenhouse (Michael, Thomas, George, & Percy, 2015). The heating has been used to reduce the relative humidity from 100% to about 85% thus reducing the possibilities of fungal growth. Greenhouse heating controls the temperature and humidity inside the greenhouse thus reducing the fungal infection preference. The geothermal fluid is obtained from a well of depth 1617m having a maximum temperature of 278℃ and an enthalpy of 1475kJ/kg. The well produces 14.7 tonnes of geothermal steam per hour. The geothermal fluid heats fresh water at the heat exchanger, the heated fresh water is then piped to the greenhouse to provide the heating needs. The hot water can also be stored in a heat storage tank of 3.8 million liters. This tank can hold hot water at temperature of 92℃. Cold water is then mixed with the water in the tank to reduce the temperatures to 50℃. (Mburu, 2014). The brine is then taken to the separator where carbon dioxide is separated from the brine via centrifugal action. The brine can be disposed into the environment while carbon dioxide taken to the greenhouse. In addition, Oserian Development Company also generates power from the two power plants with capacities 1.8 MW and 2.5MW respectively for internal use. Application of geothermal energy has reduced the amount of greenhouse gases being released into the atmosphere as well as reducing the amount spent on controlling fungal disease infections (Mariita, 2010).

Use of geothermal energy for greenhouse heating have registered numerous advantages such as clean air, fewer air borne diseases, clean water, stable work force and lower taxes (Mangi, 2014). Heating greenhouses using geothermal energy resources has saved about 80% of the fuel costs, 5% to 8% of the total operation costs compared to the use of traditional sources of energy (Mangi, 2014).

Figure 26 Geothermal greenhouse heating at Oserian Company, Kenya. (Mariita, 2010)

7.3.2 Multi-purpose utilization at Eburru

In the report, Mariita (2010) indicated that a pre-feasibility study for multiple geothermal uses i.e. electricity generation, water production for both agriculture and domestic use has already been done. In addition, drying and dehydration of agricultural products was also seen as the feasible application. These applications utilize moderate temperature uses of (40 to 100°C) which could be used to heat air for drying crops such as Onions, Pyrethrum, Pears and apples. The local communities around Eburru are already condensing steam from the fumaroles for domestic use.

Figure 27 Pyrethrum drier at Eburru using geothermal (Mariita, 2010)

In Suswa region, the local community is also harvesting water for local use from fumaroles (Mangi, 2014). Mangi (2014) stated that, water from steam in Olkaria power plant is harvested for use by wild animals within Hell’s Gate National Park.

Figure 28 Water harvesting by local a community at Suswa and Olkaria for Wildlife Use.

7.3.3 Balneological and antibacterial uses

Lake Bogoria hotel located close to Marigat in the north rift has a spa pool which uses geothermal fluids. The hot water from geothermal power stations is similar in chemistry to what is obtained from hot springs. It can therefore be used in treatment of skin diseases as well as aching muscles. This would offer semi medical treatment facilities for skin diseases (Mangi, 2014). The heat for the pool is obtained from Loboi hot spring at 38°C.

8.0 AREA OF STUDY

The assessment of agricultural products that require geothermal resource drying showed that maize crop was the best candidate. The distribution of maize crop and other cereal crops in Kenya were as shown on the figure 29 below

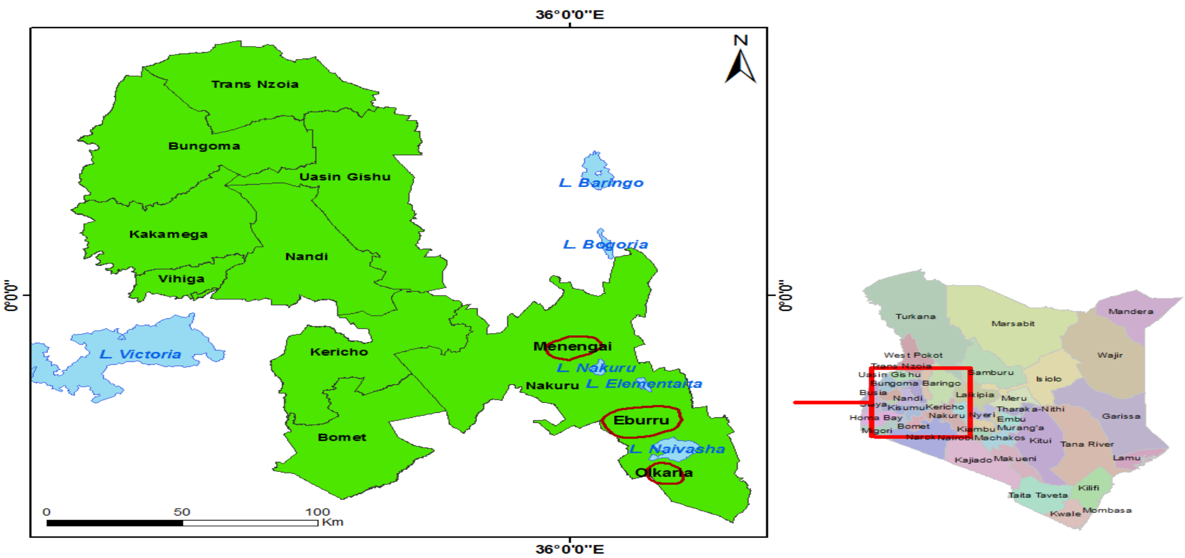


Figure 29 Large Scale maize producing regions in Kenya (Kinyanjui S. , 2013)

From figure 29 above, it was concluded that large scale maize production in in Kenya is closer to Menengai, Eburru and Olkaria geothermal fields. In this section, the average brine flow rates from the respective wells found in these fields and their enthalpy values or temperature values will be evaluated. Finally the most suitable field was selected basing on market availability and closeness to the maize crop

8.1 Menengai Geothermal Field

8.1.1 Geography of Menengai

Menengai geothermal field has high potential in geothermal energy resource and it is closer to National Cereals and Produce Board of Kenya (NCPB). NCPB deals with buying, cleaning and drying of the cereals on behalf of the farmers and for storage purposes. The most common cereals handled by NCPB include Maize, Wheat and Rice. Therefore, NCPB is one of the direct markets for the use of geothermal energy in agricultural drying. In addition, scale of maize production in the area makes it more viable to invest large scale industry than in small scale because the capital costs for geothermal drying systems.

Menengai geothermal field is situated on the out skirts of Nakuru town which is situated about 180km towards the West of Nairobi City. The field is said to cover an area of about 110km^2. .The field is well interconnected both all-weather roads and earth roads thus making it highly accessible.

The monthly weather data for Nakuru region as given by RET Screen software was found as shown in the table figure 30.

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed
	°C	%	kWh/m²/d	kPa	m/s
January	18.9	57.6%	6.98	83.0	2.2
February	20.0	51.9%	6.83	82.9	2.5
March	19.9	56.9%	6.63	82.9	2.2
April	18.7	71.4%	6.04	82.9	1.7
May	18.1	74.2%	6.33	83.1	1.7
June	17.5	73.4%	6.36	83.2	1.5
July	16.9	72.9%	6.13	83.2	1.6
August	16.9	72.3%	6.39	83.2	1.8
September	17.5	68.6%	6.69	83.1	1.8
October	17.6	70.8%	6.42	83.0	1.6
November	17.5	74.6%	5.98	83.0	1.6
December	18.3	65.7%	6.67	83.0	2.2
Annual	**18.1**	**67.6%**	**6.45**	**83.0**	**1.9**
Source	Ground	Ground	Ground	NASA	Ground

Figure 30 Weather data for Nakuru region (RET Screen, 2015)

According to Kiranga (2014), geoscientific study for Menengai geothermal field began in the year 2011. It was reported that about 20 wells had been drilled by December 2013.

8.1.2 Geology of the area

Geological studies done in the area by the geologists indicated that the main source of heat is the magmatic chamber. Over the years, the magma has erupted releasing large volumes of pyroclastic flows which resulted in the formation of the Menengai caldera. The minerals indicating the occurrence of high temperatures such as quartz, epidote and pyrite were found to appear at the average depth range of 600m to 800m at an approximate altitude of 1400m above the sea level. It was also noted that the stratigraphic sequence of the field dominantly consist of the trachytic lava. The permeability of the area has been altered by the type and degree of hydrothermal alterations and the extent or age of the tectonic activities (Montegrossi, 2015).

The figure below shows the structural scheme and location of wells in Menengai caldera.

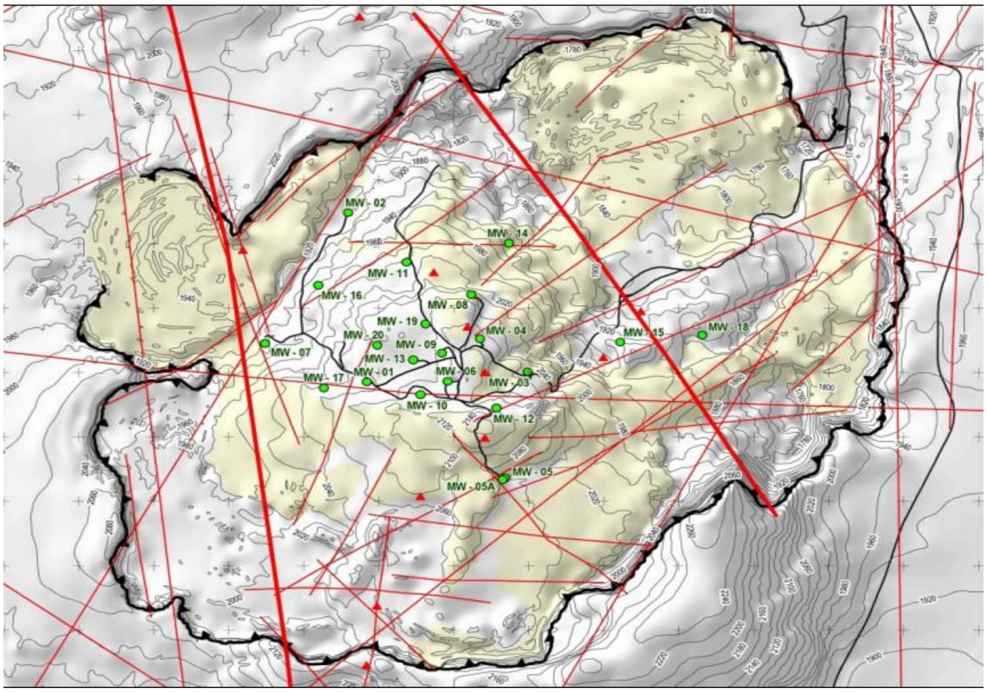


Figure 31 Structural Scheme and Wells Location in Menengai Caldera (Montegrossi, 2015).

8.1.3 Geophysics

The 80 Time-Domain Electro-Magnetics (TDEM) and 100 Magneto telluric (MT) station have been irregularly set within the Menengai caldera in order to record the geophysical characteristics of the Menengai field. From the MT data obtained, it was noted that the uppermost resistive unit at 100m -300m thickness has a resistivity range of 50 to 100Ωm respectively. In an underlying upper conductive unit of thickness between 600-800m, the resistivity range was 2-15Ωm respectively. The basement whose top corresponds to the top of the geothermal reservoir was found to have the resistivity of about 100Ωm. The resistivity at the depths around 10km to about 15km had an average resistivity of about 5Ωm which is related to deeper magmatism (Montegrossi, 2015).

The figure below shows the resistivity distribution model for Menengai caldera at sea level as developed by Geothermal Development Corporation (GDC).

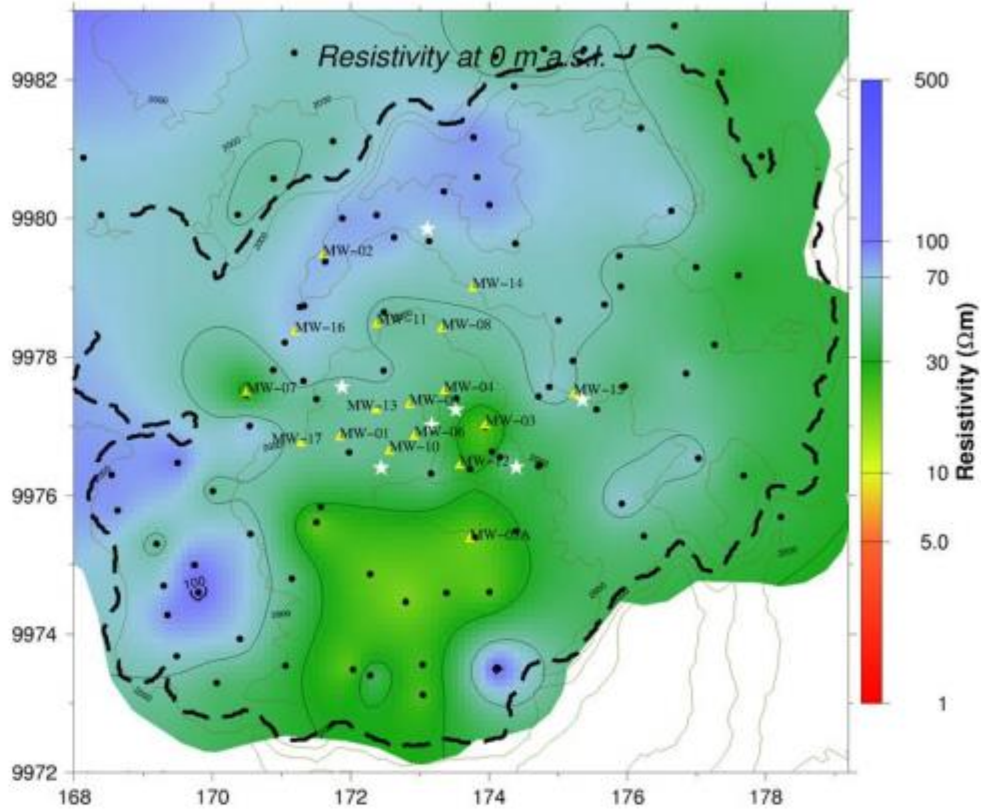


Figure 32, Resistivity distribution at sea level in the Menengai caldera (GDC, 2013)

From the model above, it was noted that high resistivity dominates the entire caldera due to high temperature alteration minerals present in the area (Kiranga, 2014).

8.1.4 Geochemistry

The geochemical data for most of the geothermal wells (MW-01, 03, 04,06,09,12 and 13) was obtained through measurements of the fluid samples taken from surface manifestations, shallow aquifers and soil gases. The samples obtained from the shallow liquid dominated reservoirs the temperatures were within 150℃ to 190℃ range. Intermediate reservoirs registered temperature range of 250℃ to 270℃. Finally, deep reservoir temperatures were ranging from 280℃ to greater than 340℃.The fluids at these reservoirs contained fluids in vapor and vapor plus liquid at mass ratios.

The Geochemical properties obtained from the seven wells in the field indicated that the chemical composition concentration in the area include: Sodium Bicarbonate with concentration of 8200 ppm (Calculated as CO2) but the general average concentration was approximately 5,000 ppm. Quartz equilibrium and Na/K Geothermometry temperatures were around 200℃ implying that the source of water was a cold zone. The carbon (IV) Oxide concentration was ranging from 1.2% to 5.7% of the total weight. The PH for most of the deep fluids was nearly neutral at (6.9) while the shallow surface fluids were fairly alkaline at PH average (9.2). Chloride concentration was found to be about >400mg/kg. H2S concentration of over 30mmol/kg was found in majority of the drilled wells. The calcium concentration was fairly low are a result calcite precipitation in the aquifers (Kiranga, 2014).

8.1.5 Brine Enthalpies and Mass Flow Rates at Menengai Geothermal Field

Table 23 Brine flow rates and Enthalpies in Menengai (Onyango, 2015)

WELL	MW-01	MW-01A	MW-04	MW-06	MW-09	MW-10A	MW-12	MW-13	MW-19	MW-20	MW-20A
MASS FLOW RATE(T/HR)	230	200	80	75	82	50	70	50	70	75	110
ENTHALPY (KJ/KG)	2000	2000	1400	2600	2600	1600	1700	2600	2000	2300	2500

Onyango 2015 modelled the optimal layout for the wells with the central separator as shown in the figure below. It was noted that any direct application using brine can be situated in about 150m from the power plant before reinjection.

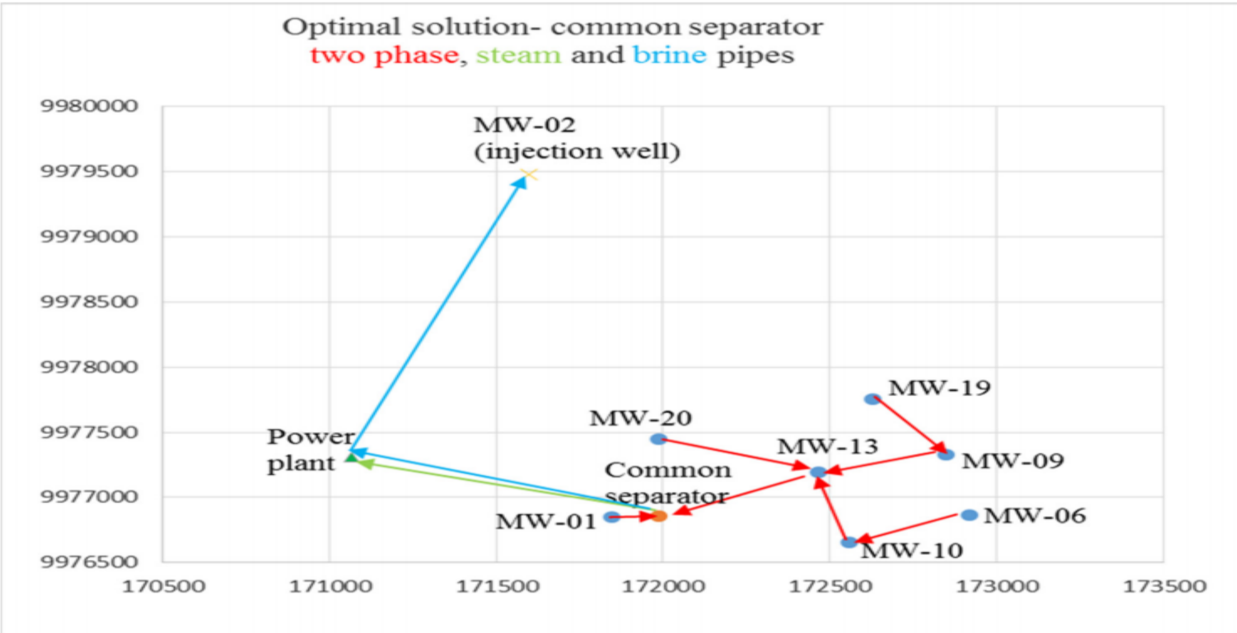


Figure 33 Optimal Layout for Menengai power plant pipeline (Onyango, 2015)

From figure 33 above, brine from the common separator can be piped to be used as the main source of heat for maize drying before being reinjected back to the field at injection well MW-02.

8.1.6 Scaling Potential

The scaling potential in the Menengai geothermal field was based on the studies done on well MW-01. It was noted that the minerals responsible for scaling in the geothermal systems are amorphous silica, calcites and anhydrates. Their saturation level was therefore determined by adiabatic boiling and conductive cooling process from the reservoir temperature and pressure conditions to about 100°C and 1 bar. The results indicated that the calcite mineral remained unsaturated on adiabatic boiling then conductive cooling to 100°C and 1bar. It could therefore be concluded that there is very limited calcite scaling in this condition. The saturation state for amorphous silica minerals approaches saturation as the temperatures are cooled towards 100°C and

1bar pressure. This therefore implies that silica scaling will occur when the fluid is cooled to temperatures below 100℃. The anhydrite mineral remains under saturated when the sample was cooled to 100℃ and 1bar conditions. Therefore, there is no likelihood scaling from anhydrite (Mundui, 2015).

The sample analysis done on well MW-03 showed that silica scaling starts as the sample was cooled to 120℃. Calcite minerals showed minimal saturation as the sample was cooled further (Mburu, 2015).

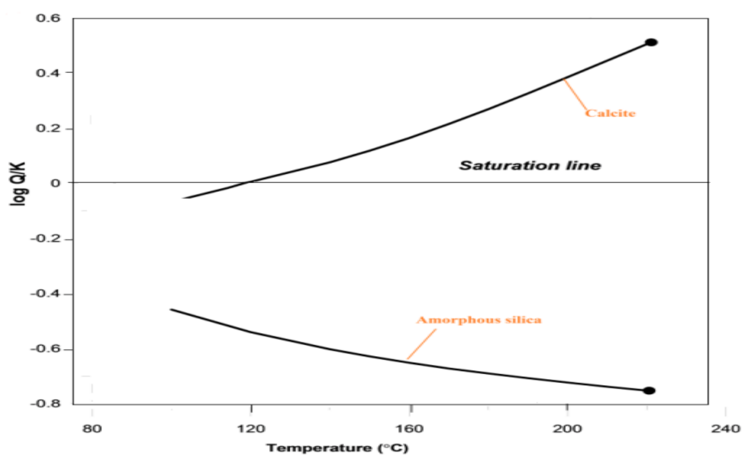


Figure 34 Calcite and amorphous silica saturation state (Mburu, 2015)

8.2 Olkaria Geothermal Field

This geothermal field is found on the floor of the Kenyan rift valley about 120km from Nairobi. (Gudni, et al., 2013). The field is said to have about 14 prospects. Most of the wells in Olkaria geothermal fields have been connected to Olkaria Power plants. The brine from the geothermal power plants at Olkaria can also be used as the candidates for geothermal drying. Olkaria (I) power plant separates geothermal fluid at 6bar pressure. The brine flow rate at 220tonnes per hour. The separation pressure at Olkaria (I) additional unit (V) is said to be at 10 bars and the flow rate of

470 tonnes per hour. Olkaria (II) power plant has a flow rate of 750 tonnes per hour at separation pressure of 6 bars. Olkaria (IV) power plant has a separation pressure of 11 bars. In addition there are a few wells that have not yet been connected to the power plants. The enthalpies and brine flow rates for these wells are as shown in the table below:

WELL	OW-805C	OW-39A	OW-46	OW-49	OW-50A	OW-50B	OW-903A	OW-907B	OW-912B
BRINE FLOW RATE(T/HR)	41.9	29.6	17	24.5	52.4	23.6	37.7	44.5	20.2
ENTHALPY(KJ/KG)	1264	1229	1825	1299	1195	1770	1537	1103	1724

Table 24 Brine Flow Rates and Enthalpy for Unconnected Wells at Olkaria Geothermal Field

8.3 Eburru Geothermal Field

This field is found within the region of maize production. Temperature characteristics for some of the wells in Eburru geothermal field is as shown in table 25 below:

Table 25 Temperature Characteristics at Eburru Geothermal Field (Mwarania, 2014)

WELL	EW-01	EW-02	EW-03	EW-04	EW-05	EW-06
TEMPERATURE (℃)	278.9	140.1	167.8	193.2	165.5	219.9

Wells EW-02, EW-03 and EW-05 lies within low to moderate temperature wells that can be used directly as the source heat for drying. In addition, brine from the separator incase all the wells are connected to generate electricity can be used as the source of heat in maize drying design.

The three possible areas were discussed above and Menengai geothermal field was considered as the preferred field for geothermal maize drying design in section 10 below. This is because of its closeness to source of maize for drying and availability geothermal resource for drying purposes.

8.4 Corrosion Potential

The chemical characteristics for most of the geothermal fields in Kenya are almost similar in nature. The geochemical analysis can be done by taking a sample of untreated fluid and steam. The samples collected were then subjected to the determination of PH, total dissolved solids (TDS), total carbonate carbon (TCC), Cl, B and non-condensable gases (Kipng'ok, 2011).

The results from the chemical analysis at well MW-01 at Menengai geothermal field as found by (Kipng'ok, 2011) was recorded in the table below:

Water sample (PPM)		Steam Sample (mmol/kg)	
PH	6.3	CO_2	142.5
SiO_2	283	H_2S	3.5
B	0.13	H_2	14.4
Na	2364.5	CH_4	3.9
Ca	0.9	N_2	25.8
Mg	0.005	O_2	0
εco_2.	6589		
SO_4	212.4		
H_2S.	37.4		
Cl	774.8		

Table 26 Chemical Composition for Well MW-01 at Menengai Geothermal field (Kipng'ok, 2011)

It was assumed that most of the well in Menengai geothermal field have almost similar chemical characteristics. Therefore, the chemistry for well MW-01 was considered in feasibility study for this project.

The chemical components exist in a chemical equilibrium state. The changes in PH and temperatures causes instability in their state. This dissociates them into cations or anions to gain new equilibrium (Mundhenk, et al., 2013). These ions include $CL^-, H_2S, SO_4^{2-}, HCO_{3-}, H+, F-$ and H_2S/HS^-. These ions might then react with the surface of the metal surface to cause corrosion.

The most likely factors to influence the rate of corrosion on the geothermal drying components might be affected by the factors listed below:

8.4.1Temperature

The increase in temperature leads to increase in corrosion provided all other factors causing corrosion are kept constant as a general rule. However, the solubility of most gases in open systems is lower at higher temperatures. As the solubility of the gases increases with increase in temperatures, corrosion rates will go down (Nikos, Pierre, & Petros, 2010). The operating temperature should not be too high to cause corrosion nor low to cause scaling.

8.4.2 PH

Corrosion rates increases with the reducing PH value. The reduced PH directly increases the concentration of aggressive hydrogen ions and increases the solubility of most of the corrosive products in the geothermal fluids (Nikos, Pierre, & Petros, 2010). The heating fluids are therefore required to be operating within the required PH value.

8.4.3 Oxygen concentration

Oxygen acts as an oxidizing agent in corrosion process. The increase of oxygen concentration in the system increases the rate of corrosion till the point at which the rate of diffusion on the surface is at maximum (Nikos, Pierre, & Petros, 2010). The piping system should be sealed to prevent entry of oxygen into the system.

8.4.4 Fluid velocity and Suspended solids

The general rule states that the rate of corrosion increases with an increase of the velocity of the geothermal fluids. However, as the fluid velocities increases from stagnant to moderate velocities, there is increase in corrosion rate. As the diffusion limit at that temperature is reached, an increase in velocity has no influence on the rate of corrosion (Nikos, Pierre, & Petros, 2010).As the level of suspended solids increases, the rate of corrosion also increases.

9.0 POTENTIAL ENVIRONMENTAL IMPACTS AND THEIR MITIGATION

Geothermal utilization projects should be design to meet economic, social and environmental sustainability (Pierre & Nikos, 2010). Strategic optimization ought to be done prior to commencement of the project to ensure the operations are within the sustainable development agenda. Geothermal resources and utilization including geo-drying has been considered as one of the most environmentally friendly energy resource. However, it may cause some environmental sensitive impacts when not handled carefully. These impacts whenever overlooked or ignored may lead to disputes within the stakeholders leading to project abandonment. Environmental safety considerations should therefore be put in place at all phases of geothermal development and utilization. In case geothermal heat for grain drying is being recovered from the brine or the condensate from the turbines, then environment impact assessment is done from the point where the condensate or brine is being utilized. For actual geothermal fluid from production well, environmental factors should be considered from the exploitation to utilization stages.

In this section, the possibility impact of this project on soil, water, social and air will be highlighted. Lastly, the possible mitigation, measures to some of these impacts will be proposed.

9.1 Impact on water quality

Geothermal waste fluids such as separated brine and steam condensate can have a direct impact both on subsurface and surface water when poorly discharged. Discharging in the nearby water body affect the aquatic life, domestic water use, water for irrigation and even death of livestock. The discharges also may alter the temperature of the water body when released in without cooling it to the required temperature. The PH value may also change depending on the PH level of the fluid being released into water. Seepage of the geothermal fluid contaminates underground water (Pierre & Nikos, 2010). Some of the chemicals that may contaminate the water bodies according to Brown 2005, include: Hydrogen sulphide (H_2S), Ammonia (NH_3), Boric acid (H_3BO_3), Mercury (Hg), Arsenic (As), Lithium (Li).

9.2 Effects on Environmental air

Atmospheric emissions in geothermal utilization projects may occur during well discharge, drilling and geothermal systems operations. According to (Pierre & Nikos, 2010), there are very minimal greenhouse gases (GHG) released in the binary geothermal systems are very minimal. It was recorded that such systems do not emit nitrogen IV oxide gas while the amount of carbon dioxide released in the atmosphere is comparatively lower than the amount released by coal and natural gases. Binary systems eliminate any possible emissions unless in an event of an accident gases such as Methane, Carbon Dioxide, and Nitrogen and hydrogen sulphide can be emitted into the atmosphere.

The acidic gases such as carbon dioxide and hydrogen sulphide, and mercury may lower the PH value of the blood when inhaled causing breathlessness and dizziness when taken in large quantity. Carbon dioxide and hydrogen sulphide gases can severely endanger the health of human beings and other living things. The mercury content although in small quantity, it should be carefully be monitored. Continuous exposure of mercury may accumulate in the food chain in an ecological system and may lead to irreversible damage of the central nervous system. Ammonia has unpleasant toxic characteristics that can affect the human physiology (Pierre & Nikos, 2010).

9.3 Mitigation measures

There should be the minimized exposure time by the geothermal system personnel as recommended by World Health Organization (WHO). WHO recommends that the workers should be protected from exposure through remote, more sensitive gas monitoring protocols and gas abatement processes should be put in place before project implementation commences (Pierre & Nikos, 2010).

9.4 Impact of physical environment

Almost all the geothermal systems development greatly modifies the nature of an existing environment. Development of geothermal structures results in clearing of the existing vegetation. Underground water abstraction causes land subsidence as a result of reduced pore pressure. Micro seismic occurrences may be induced during drilling of geothermal wells and injection activities. Cold water injection may also cause thermal stress cracking which causes land subsidence and seismic action (Pierre & Nikos, 2010).

9.5 Social impacts

Any geothermal project development has to be accepted by the local community. In case the local community is ignored in geothermal project development, the hostility from the community may lead to stopping of the project at any development stage. The operators should therefore focus on the project acceptance. The expected social-economic benefits such as job creation, externalities and the consequences on the ecosystem and the habitants should be disclosed in a very transparent manner (Pierre & Nikos, 2010).

The table below shows a summary of the impacts of the geothermal drying system and the possible mitigation measures.

Impact	Damage	Risk level	Mitigation measure
Soil Water Human settlement	Soil erosion, vegetation loss Human transfer	Medium Low High	Reforestation programme Compensation of human resettlement
Water	Change in water shed & water table. Land subsidence Induced seismology	Medium to high Medium to high Medium to high	Minimize withdrawals Use of reinjection Proper reservoir management.
Atmospheric emissions	Breathing problems Chemical Emmisions Odd smells	High High Low	Toxic gas abatement (H2S scrubbing), Fixing of non-condensable gases.

Table 27 Possible Environmental Impacts by Geothermal Systems (Pierre & Nikos, 2010)

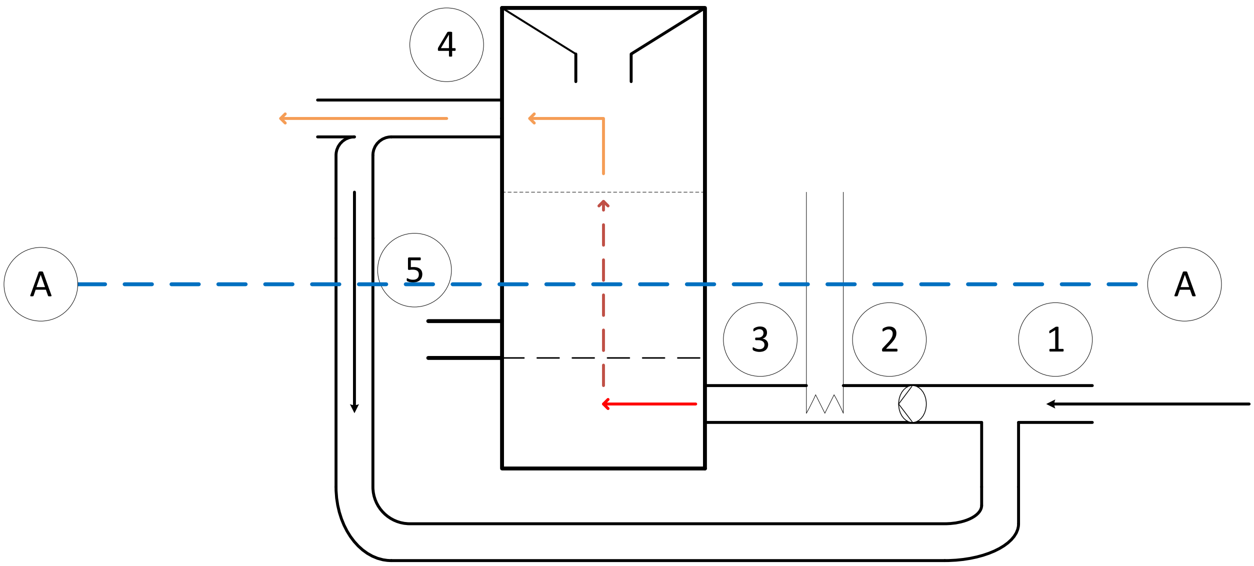
The table below indicates the waste water limits according to WHO. The geothermal fluid used for drying in this project should be within these limits.

Table 28 WHO waste water limits (Oduor, 2010)

Waste water parameter	Maximum concentration (mg/l)
Biological Oxygen Demand (BOD)	50
Chemical Oxygen Demand (COD)	250
Total Suspended Solids (TSS)	50
Oil and Grease	10
Heavy metals (Total)	10
Total Chromium as Cr	0.5
Total copper as Cu	0.5
Total iron as Fe	1.0
Total Zinc as Zn	1.0
Total Chloride as Cl	0.2
Total Arsenic as As	0.1
Total lead as Pb	0.1
Total Mercury as Hg	0.01
Total Nickel as Ni	0.5
Ph	6-9unit less

10.0 MAIZE DRYING DESIGN

The schematic diagram of the proposed maize dryer was as shown in the figure below:



The ambient conditions at point [1] were obtained as the weather conditions of the Nakuru where the proposed maize dyer is to be installed. The drying temperature [T_3] at point [3] was set as obtained from the literature as the maximum recommended maize drying temperatures. The relative humidity [RH_4] of the drying air at the exit was set as the equilibrium relative humidity obtained from the relationship of water activity and the equilibrium maize moisture content. The air recirculation of (r=0.6) was considered to increase the effeciency of the dryer and maintain the drying conditions to avoid kernel breakage.

The known values of RH [1], T [1], P [1], T [3], RH [4] and recirculation ratio were used as the inputs in the Engineering Equation Solver (EES). The rest of the values were generated from the relationship equations and the input figures. The results were generated on the array table as shown on the table 29.

Main

Sort	1 h_i [kJ/kg]	2 ω_i [kg/kg of air]	3 P_i [kPa]	4 RH_i	5 s_i [kJ/C]	6 T_i [C]
[1]	45.26	0.01069	83	0.675	5.829	18.1
[2]	70.33	0.01699	83	0.6231	5.829	26.88
[3]	87.05	0.01699	83	0.2552	5.969	43
[4]	87.05	0.02119	83	0.555	5.971	32.62
[5]	87.05	0.02119	83	0.555	5.971	32.62
[6]	87.05	0.02119	83	0.555	5.971	32.62

Table 29 Psychometric Dryer Design Parameters and Results (Engineering Equation Solver(EES), 1992-2015)

The designed dryer was represented of the Mollier graph as shown below:

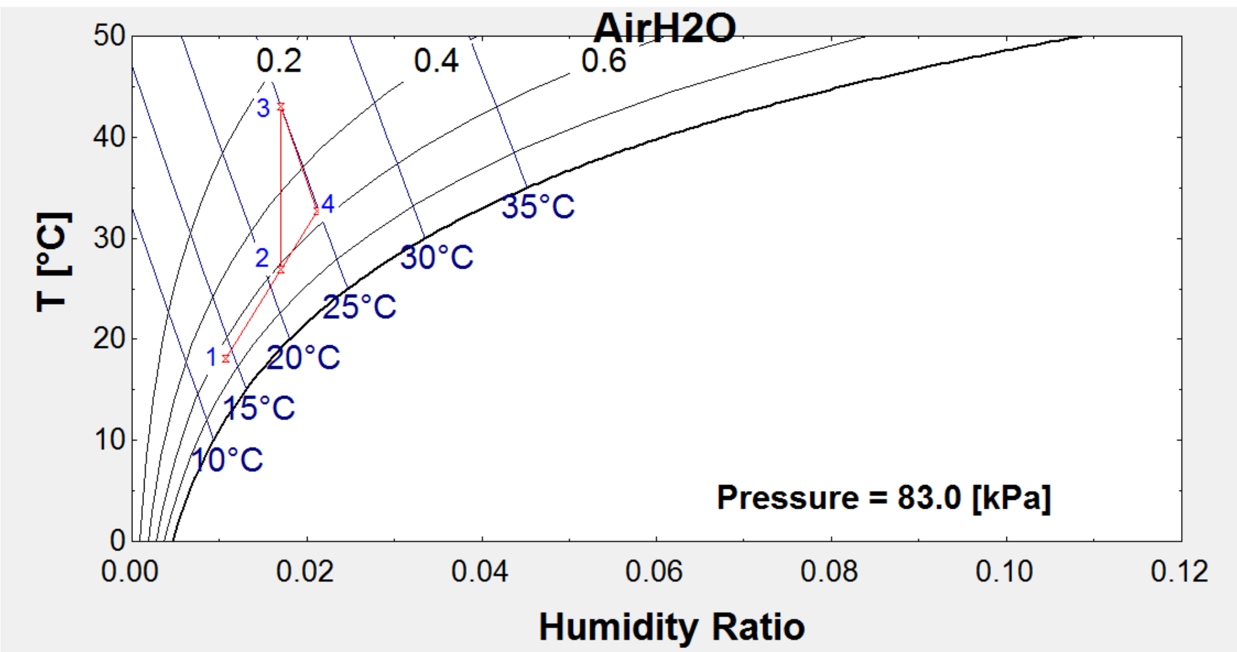


Figure 35 Mollier Graph for Maize Dryer at Menengai (Engineering Equation Solver(EES), 1992-2015)

There are several parameters and properties to be determined in design of the most efficient drying systems. These parameters and properties can be determined as shown below (Fashina Adepoju, Akande, Ibrahim, & Sanusi, 2013):

10.1 Moisture of Product at Harvest

The moisture content in the maize grain can be found both as the wet basis or dry basis. The wet basis moisture content was found using the formula below:

$$MC_{wb} = \frac{\text{Mass of Water}}{\frac{\text{Mass of the sample}}{(\text{Mass of water+Mass of solids})}} \times 100 \qquad 8.$$

The Dry basis moisture content was to be found using the formula below:

$$MC_{db} = \frac{\text{Mass of Water}}{\text{Mass of solids}} \times 100 \qquad 9.$$

The mass of water used in the calculation was obtained as the difference between the mass of the wet maize sample and the mass of the dried maize sample as shown in the formula below:

$$\text{Mass of water} = \text{Mass of wet maize sample} - \text{Mass of dried maize sample}$$

This was to be done by taking the mass measurement of the wet maize before being placed in an oven. The weight of the drying sample is taken at an interval until there was no further mass reduction. The final weight was then taken as the mass of the dried sample. The mass measurement was to be done when the sample has could and attained the equilibrium ambient conditions. The mass measurement is recommended to be done on a digital scale of about 0.01g accuracy.

Since there were no sample and equipments to determine the moisture content of maize at harvest, the theoretical value for initial moisture at harvest was picked to be 25% wet basis. While the dry basis moisture content was calculated to be 33.3%.

The final moisture content safe for storage for the storage of about 1 year was obtained from literature as 12% wet basis while the dry basis was found to be 13.6%

10.2 Amount of Moisture to be removed (M_R)

The amount of moisture to be removed from the dried was obtained using the formula below:

$$M_R = M\left[\frac{MC_{Initial(wb)} - MC_{Final(wb)}}{1 - MC_{Final(wb)}}\right] \qquad 10$$

Where:

M = Dryer Capacity per batch = 35000kg.

$MC_{Initial(wb)}$ = Initial moisture content of the material to be dried = 0.25.

$MC_{final(wb)}$ = Maximum desired final moisture content = 0.12.

M_R = Moisture to be removed (kg).

Using the initial maize grain and final moisture content wet basis, the amount of water to be removed from the one batch of maize was found to be:

$$M_R = 35000\left[\frac{0.25 - 0.12}{1 - 0.12}\right] = 5170 \text{ kg.}$$

10.3 Quantity of air Required for Drying

The amount of air required to completely remove the amount of moisture from the maize sample being dried was found using the formula below according to (Fashina Adepoju, Akande, Ibrahim, & Sanusi, 2013):

$$Mass_{air} = \left[\frac{M_R}{\omega_4 - \omega_3}\right] \qquad 11$$

Where:

$\mathrm{Mass_{air}}$ = Quantity of air required for drying.

ω_4 = A mount of moisture content in air leaving the dryer (kg/kg of dry air) = 0.02119kg/kg of air

ω_3 = A mount of moisture content in air entering the dryer $\left(\frac{\mathrm{kg}}{\mathrm{kg}}\text{of dry air}\right) = \frac{0.01699\mathrm{kg}}{\mathrm{kg}}$ of air.

$\mathrm{M_R}$ = Moisture to be removed obtained from section above.

The value of ω_3 was taken as the value of the water content in the air mixture of the air being taken from the environment and the recirculating air. The amount of water in the air coming from the environment and the recirculated air were obtained from the EES software then using the recirculation ration of 0.55 the value of ω_3 was obtained. The value ω_4 was also obtained by EES after inputting the equilibrium relative humidity (ERH) which was taken as the relative humidity at exit ($\mathrm{RH_4}$) and the enthalpy (h_4) which was taken to be equivalent to enthalpy of the drying air (h_3).

Using these values, the amount of air required was therefore obtained to be

$$\mathrm{Mass_{air}} = \frac{5170}{0.02119-0.01699} = 1{,}230{,}953 \text{ kg of dry air.}$$

10.4 Volume of air needed for drying

The volume of air needed per batch drying was obtained from the formula below (Fashina Adepoju, Akande, Ibrahim, & Sanusi, 2013):

$$\mathrm{Volume_{air}} = \frac{\mathrm{Mass_{air}}}{\delta_a}. \qquad 11$$

Where:

δ_a = Density of the air in $\frac{Kg}{m3}$ determined at 43°C at given as 1.118 $\frac{kg}{m^3}$ (Obtained from the fluid properties table).

Therefore, it was obtained to be

$$\text{Volume}_{air} = \frac{1230953}{1.118} = 1101030m^3$$

10.5 Heat requirement for drying process

The amount of energy required to remove the amount of moisture per batch of maize is a function of

$$Q_a = \text{Mass}_{air}(h_3 - h_2) \qquad 12$$

Where:

Q_a = Heat requirement for batch drying in kJ.

Mass_{air} = Total amount of air needed for batch drying in Kg.

h_2 = Enthalpy of air entering the heat exchange in $\frac{kJ}{kg}$ of air.

h_3 = Enthalpy of drying air leaving the heat exchange in $\frac{kJ}{kg}$ of air.

$Q_a = 1230953(87.05 - 70.33)$=20.6× 10^6kJ

The time needed to dry one batch of maize from literature was found to be 18 hours according to (Atul & Chen, 2008).

Therefore, the amount of air and energy needed to dry maize per hour was found to be:

$$\text{Mass per hour} = \frac{1230953\text{kg}}{18\text{hr}} = 68{,}386\text{kg/hr.}$$

$$\text{Amount of heat per hour} = \frac{20.6\times10^{6}\text{kJ}}{18\text{hr}} = 1143418\text{kJ/hr.}$$

10.6 Selection of heating element

The energy the air mixture coming from the ambient environment and the recirculated air was found not enough to dry the maize batch. The temperature and the enthalpy of the mixed air at point [2] was found to be 26.88℃ and 70.33kJ/kg respectively. This was to be heated to temperature of 43℃ and enthalpy of 87.05kJ/kg at drying condition at point [3]. The radiators will therefore be used as a liquid-air heat exchanger.

The source of heat was from well MW-03 whose enthalpy was found to be 1250kJ/kg. From the scaling limit calculation, it was found that the brine in this well starts forming scales as the temperatures cools beyond 120℃. Using this temperature, the pressure of brine from the separator and the specific heat capacity of brine as the inputs, the enthalpy at 120℃ was found to be 477.6 kJ/kg.

The amount of energy needed to dry the batch of maize is equal to the amount heat supplied by the geothermal fluid as shown in the equation below:

$$Q_a = M_{geo}\Delta h \qquad 13$$

The mass of geothermal fluid needed per hour was found to be:

$$M_{geo} = \frac{\frac{1143418\text{kJ}}{\text{hr}}}{(1250 - 477.6)\text{kJ/kg}} = 1480\text{kg/hr}$$

10.7 Drying Chamber Dimensions

The dimensions of the drying chambers depend on the configuration of the dryer i.e. whether cylindrical, cuboidal or cubicle and the amount of material to be dried per batch. In this project, the cylindrical type dryer was chosen because of the ease in turning and uniformity in drying air flow. From the literature, it was found that the recommended grain depth in deep grain drying ranges from 2 to 5m. The grain depth of 5m was considered in this project in order the use the minimum diameter. Using the maize bulky density of 720kg/m^3 according to (Fashina Adepoju, Akande, Ibrahim, & Sanusi, 2013).the volume of 35000kg of maize per batch was found to be 48.61m^3. Assuming that the porosity of the maize gain is about 0.48, the total volume of maize and the spaces was found to be 93.5m^3.Therefore, taking 5m as the grain depth as stated above, the radius of the dryer was calculated and found to be 2.4m

The velocity of the air was therefore given by formula below:

$$\mathrm{v} = \frac{\mathrm{V_a}}{\mathrm{A_{CR}}} \qquad 14.$$

Where:

v = Air speed in m/s.

$\mathrm{A_{CR}}$ = Dryer Cross section area.$18\mathrm{m}^2$

$\mathrm{V_a}$ = Volume of air required for drying. $(17\frac{\mathrm{m}^3}{\mathrm{s}})$

The velocity therefore was calculated using equation 12 as

$\frac{17}{18} = 0.94\mathrm{m/s}.$

10.8 Pressure Drop

The difference drop (ΔP) across the maize drying bed column depends on the density difference in density between the hot air in the drying chamber and the ambient temperature (Gunasekaran, Jindal, & Shove, 1982). In calculation of the airflow and pressure drop created by the temperature differences the following assumptions must be made: uniform air density in the dryer, the dryer is airtight and hot air outlet is only through the outlet chimney, and negligible airflow resistance on the dryer components (Gunasekaran, Jindal, & Shove, 1982).

Therefore, the pressure drop can be given as (Gunasekaran, Jindal, & Shove, 1982):

$$\Delta P = \Delta \rho * g * H \qquad 15$$

Where

$\Delta P = \text{Pressure drop.}$

$\Delta \rho = \text{Density difference depending on dry temperature and ambient temperature.}$

The density difference between the atmospheric temperature at 18.1℃ and the drying temperature at 43℃ used in this design is 0.09kg/m^3.

G=acceleration due to gravity (9.81N/kg)

H=the pressure head (height of the hot air column from the base of the dryer to the point of air discharge from the dryer), in (m).

This can give use the general equation:

$$\Delta P = 0.8829H.$$

Considering the grain depth of 5m and the air exit at 1m above the grain level, the total H value was found to be 6m.

Therefore, replacing H in equation 13 above gives pressure difference of 5.3N/m^2.

10.9 Fan capacity, design and selection

Fans and blowers in the drying system are used to transfer heated air from the heat exchangers across the drying materials in the dryer cabinet. Their selection normally depends on the volume of air needed in the drying process. Other fan selection parameters such as minimum fan power requirement and fan drop pressure can be calculated from the volume of air value (Fashina Adepoju, Akande, Ibrahim, & Sanusi, 2013). The fan models and types are then selected from the fan manufacturers' catalogue. Most drying designs set the fan drop pressure at about 450Pa (Tesha, 2006).

The relationship among the key fan and blower design parameters can be obtained from the relationship given below according to Tesha (2006):

$$P_{fan} = \frac{V_a \, \Delta p}{\mu_{fan}} \qquad 16$$

The power of the motor to run the fan or the blower can be obtained from the formula below:

$$P_{motor} = \frac{P_{fan}}{\mu_{motor,fan}} \qquad 17$$

Where:

P_{fan} = Fan power (W).

V_a = Volume of air needed (m^3/s).

Δp = Pressure drop (Pa).

μ_{fan} = Efficiency of fan.

P_{motor} = Motor power (W).

$\mu_{motor,fan}$ = Efficiency of fan motor.

10.10 Drying Time

In his research, Folaranmi (2008), used a solar collector to dry about 50kg of maize at 45℃ to dry maize. It was found that the drying took 3 days of 9 drying hours each day to reduce the moisture content to be 12.5%. The exhaust temperature was found to be 32℃ thus giving it a temperature difference of 12℃ which is the same the temperature difference considered in this design (Folaranmi, 2008). The parameters in this solar dryer design were used as the basis in calculation drying time in this project. According to (Adebayo, 2014), the average sun hours in Nigeria are about 6hrs. It can therefore be concluded that the effective drying time in solar dryer considered was 6hrs thus giving a total drying time of about 18hrs. The drying time in this design is therefore assumed to be the same as the effective drying time found in solar dryer mentioned above that is 18hrs.

10.11 Heat Exchangers Design

Selection of heat exchangers by vendors have been done by the specific selection software. However, designers can apply the general rule of thumb in order to define temperatures and flows before making an order to the vendor. The key parameters in selection of plate heat exchangers is the heat transfer area.

The general formula for calculation of performance of the heat exchanger used in geothermal maize drying system is as given below:

$$Q = U \times A \times LMTD \times C_f \qquad 18$$

Where:

Q=Heat load in (W).

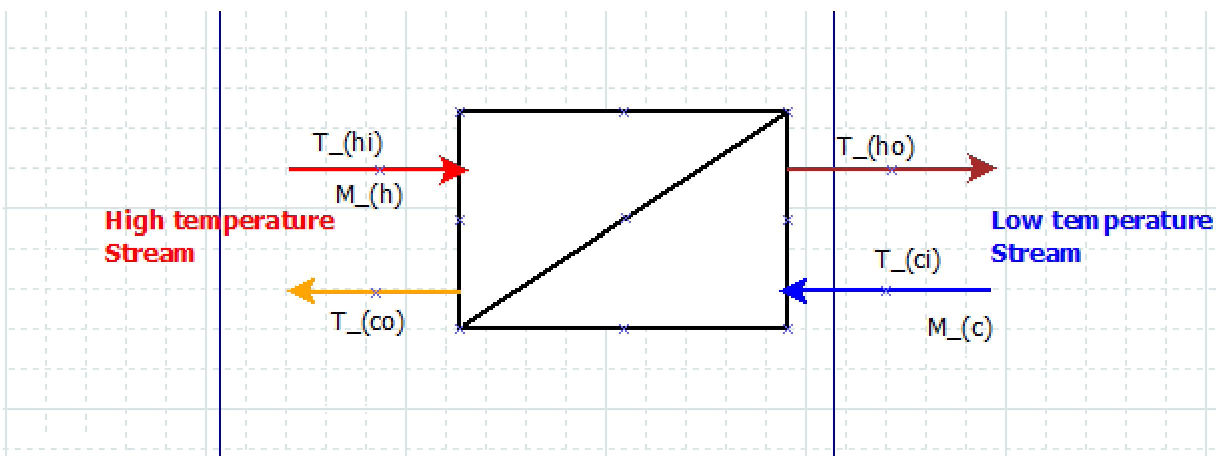
U=Overall heat transfer coefficient ($W/m^2 °C$)

LMTD=Logarithmic mean temperature in °C

A=Area (m^2)

C_f=LMTD correction factor (0.85-1.0) for most geothermal applications

The logarithmic mean temperature difference (LMTD) was calculated using the differences in temperature entering and leaving the heat exchanger.as shown in the equation below:



$$LMTD = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} \qquad 19$$

Where:

$\Delta t_1 = T[hi] - T[co]$ (Temperature difference in high temperature stream)

$\Delta t_2 = T[ho] - T[ci]$(Temperature difference in low temperature stream)

T[hi] =Temperature of geothermal fluid at the inlet

T[ho] =Temperature of the geothermal fluid at the outlet

T[co]=Temperature of the drying air outlet

T[ci] =Temperature of the drying air inlet

Using equation 16 above, the LMTD for the heat exchange in this design was found to be 98.8℃ .The heat exchangers available on the market are either made of polypropylene whose thermal conductivity is about 0.1W/(m K), stainless steel whose thermal conductivity is 16W/(m K) or aluminum whose thermal conductivity is 205W/(m K). Assuming that the convective heat transfer for air is about h_{air} is 50W/m^{2}K, the wall thickness of about 0.1mm, then the overall heat transfer coefficient (U) for the three materials were found to be 24.4 W/m^{2}K, 25 W/m^{2}K and 25 W/m^{2}K respectively.

Therefore, using the equation for calculation of performance of heat exchanger 15 above, replacing the other parameters, the heat exchanger area was found to be 128.6m^2.

11.0 ECONOMIC ANALYSIS FOR THE PROJECT

The agricultural products and geothermal resources assessment as well as technical analysis have shown that geothermal drying is viable in Kenya. However, economic viability plays a key role in whether the project attracts investors for financing. In order for the project to attract investors, it must be able to generate revenues. Whenever the costs are more than the benefits, then the project is not viable for investment. In this section, the total costs and benefits were evaluated. The main types of costs considered in this project were: capital or initial investment costs and operation and maintenance costs.

11.1 Capital Investment Costs

The initial costs in this project were obtained by approximating the costs for civil works at drying station, costs of equipments such as heat exchangers, piping systems maize dryer etc. and installation costs. The heat exchanger and dryer costs constituted the largest portion in capital costs.

11.2 Operation and Maintenance Costs

These costs constituted the costs of electricity needed to run the electrical equipments, costs for maintaining the drying equipments and the labour costs. This cost was assumed to be 15% of the investment cost while the project depreciation was estimated to be 1% of the initial cost

The maize drying plant was preferred to be set up near the source of the geothermal heat to minimize piping costs. Operation of the geothermal grain drying system can be done by a few employees.

The costs and benefits the sample maize dryer were given in the table below

ITEM	SPECIFICATIONS	PRICE($)
Heat exchanger		44,800
Batch dryer		65,000
Piping System	Steel (150m)	30,000
Construction cost		60,000
TOTAL INVESTMENT COST		199,800
Depreciation 1% of investment cost		1,998
Operation & maintenance cost. 15% of initial cost		29,970
TOTAL PROJECT COST		231,768
BENEFITS		
Income from Drying one Batch	$195 per Batch	$66,300 Per year

Table 30 Cost and Benefits

The cost benefit analysis of the project using Net Present Value (NPV) decision making tool was done. In the analysis, the lifespan of the project was set at 20 years according the life span of the main components of the system i.e. the batch dryer and the heat exchanger. The interest rate according to Central Bank of Kenya 2016 was 10.5%. Using this rate, the NPV was found to $82784. Since the NPV is positive, the project is therefore economical feasible. The use of PAYBACK period decision making tool found out that the project can payback the investment cost in 5years, 1 month and 1 day. Since the payback period is less than 20 years, the project can be considered worth investment. The Internal Rate of Return (IRR) was calculated and found to be 18% which is greater than the interest rate in Kenya which is 10.5%. It could therefore be concluded that the project is economically feasible.

12.0 CONCLUSSION

The objectives of this project was to carry out a prefeasibility study on use of geothermal heat for drying of agricultural products and to design geothermal drying system for the highest product at the preferred geothermal field. The crop assessment in Kenya indicated that maize is the most produced crop in Kenya. Therefore, maize crop was taken as the candidate for geothermal drying. The amount of maize being produced per county in Kenya and it was noted that rift valley, western and nyanza regions are the highest maize producing regions in Kenya. Rift valley is said to produce about 80% of the total maize produced in Kenya while Western and Nyanza combined produces about 14% of total maize produced.in Kenya. Menengai geothermal field was chosen as the field of study because of its proximity to the maize producing areas and abundance of geothermal resource. It was noted that the product for drying and the geothermal resource availability were in abundance and could not be the limiting factors. However, other logistical factors such as transportation and storage were found to some of the limiting factors. Considering all these factors, a dryer of capacity 35000kg per batch was chosen. The amount of geothermal brine needed for drying considering the temperatures and scaling limits for of the wells in Menengai fields was about 1.5 tonnes per hour. Using Net Present Value (NPV), decision making criteria it was found that the project yields $82784 in 20 operating years. The payback period for the project was found to be 5 years, 1 month and 1 day. Whilst the internal rate of return (IRR) was found to be 18%. It can therefore be concluded that use of geothermal heat for drying of agricultural product is technically and economically feasible.

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