DEVELOPMENT AND PERFORMANCE EVALUATION OF A RICE HUSK FUELED PADDY DRIER FOR USE IN MWEA IRRIGATION SCHEME IN KENYA

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Development and Performance Evaluation of a Rice Husk Fueled Paddy Drier for use in Mwea Irrigation Scheme in Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This thesis is dedicated to my parents for having seen me through my education. Also to my wife Lilian, and the children that is Brian, Ivy and Lewis for the support and understanding that they gave me during the period of my studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS

Symbol	Description
B	Feed rate of rice husks kg/h or husk burning rate
Cpg	Grain specific heat capacity of the grains
Cc	Calorific value of rice husks in kJ/kg
Dh	Design parameter of rice husks
ξ	Crop porosity
εv	Loading bed void fraction
hL	Layer drying bed thickness
h1	Specific enthalpy of air at inlet
h2	Specific enthalpy of air at outlet
LV	Latent heat of vaporization
Maf	Air mass flow rate
Mg	Mass of the grains dried
Mw	Quantity of moisture to be removed
Ma	Mass of air required to remove moisture from the product
MH	Quantity of rice husk needed for combustion
Mw	Mass of evaporated water
n	Pickup factor which is a ratio
ρgr	Bulk density of the crop
Q	Total Energy from rice husks
q	Energy required for drying
T1	Initial temperature of the drying air
T2	Final temperatures of the drying air
ΔT	Temperature change of drying bed
V	Volume of the combustion chamber
Vs	Specific volume
ΔWCB	Change in humidity ratio
WW	Mass of the crop to be dried
η_h	Biomass heater efficiency

ABBREVIATION

Abbreviation	**Description**
ANOVA	Analysis of Variance
EMC	Equilibrium Moisture Content
FMC	Final Moisture Content
FAO	Food Agricultural Organization
GHG	Green House Gases
HRY	Head Rice Yield
KIRDI	Kenya Industrial Research and Development Institute
KEBS	Kenya Bureau of Standards
LPG	Liquefied Petroleum Gas
NIB	National Irrigation Board
SHUE	Sensible Heat Utilization Efficiency
TOE	Tones Oil Equivalent
UPLB	University of Philippines Los Banaos

ABSTRACT

There are many methods for grain drying including open sun drying, solar drying and mechanical drying. The problems with open sun drying include contamination, and poor drying performance during rainy and cloudy seasons leading to high post-harvest losses. The use of alternative and renewable energy sources including agricultural waste is becoming common with emergence of new combustion technologies and increasing costs of conventional fuels. This study undertook a field survey in Mwea Rice Irrigation scheme to gather technical data to assist in developing a rice husk fueled paddy drying system. The survey was conducted via questionnaires in which 300 farmers and 20 millers were interviewed. From the field survey findings, it was observed that about 98% of farmers desired to have low cost dryers that uses low cost energy source for paddy drying. This is because harvested paddy rice at a moisture content of 25% to 26% (wb) required further drying. On the other hand, 100% of the millers experienced challenges in drying newly harvested paddy because of high moisture content. The millers had challenges disposing the rice husk generated as 100% of millers had to damp and burn the husks in the open yard. Therefore, a model rice husk fueled paddy dryer capable of drying 250 kg per batch of harvested paddy was designed and fabricated at KIRDI. Paddy at a moisture content of 26% was dried to 14% (wb) in 4 hours. The combustor efficiency was computed to be 64% with consumption of 2.6 kg rice husks per hour. The emissions from the combusted husks were evaluated using flue gas analyzer and found to be 7% to 11% for CO_2, 42.6 to 77.6 ppm for CO, 32 to 39 ppm for SO_2 and 99.8 ppm to 104.3 ppm for NO_2. It was observed that incorporating an exhaust fan on the flat bed dryer resulted in achieving in uniform moisture content across the bed height. From the economic analysis, the dryer shows a short payback period of 1.5 years and a cost benefit ratio of 1.4. On the basis of these findings, it was concluded that the developed dryer is economically viable and should be promoted in Kenya and other countries for paddy drying.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Globally rice is one of the most important food crops in the fight against hunger. The total annual world production of milled rice currently stands at 400 million metric tons which compares favorably well with maize and wheat (Ministry of Agriculture, 2009). In addition, unlike maize and wheat which are consumed as human and livestock feed, rice is still the most favored grain globally being consumed in households. It is estimated that Kenya consumes about 300,000 metric tons annually while the country produces about 45,000 to 80,000 metric tons of rice per year (Ministry of Agriculture, 2008). Promotion of rice cultivation combined with postharvest management will result in the improved food security, increased small holder farmers' income, result in employment opportunities in rural areas and a reduced the rice import bill (Ministry of Agriculture, 2009).

According to Kenya Ministry of Agriculture, growing of rice in Kenya was started in 1907 as adopted from Asia. This crop is currently the third most important cereal crop after maize and wheat in the country. It is normally grown by small-scale farmers for commercial and subsistence purposes in Mwea, Ahero, West Kano, Bunyala, and Tana delta irrigation schemes. About 80% of the rice that is grown in Kenya is obtained from the irrigation schemes established by the Government while the remainder of 20% is cultivated under rain-fed conditions (Ministry of Agriculture, 2009).

Mostly after harvest, the rice is normally sun dried outside and then threshed. The husks generated are mostly burnt in the fields or dumped on the road side. Waswa *et al. (*2002) noted that the quantity of rice husks generated annually in Kenya was about twenty percent of the total rice produced which translates to 9,000 to 16,000 tons. After harvesting grains, one of the first processes is to have the grains dried well to minimum moisture content before storing them in the stores. This will ensure that the grains are not infested by insects besides other micro-organisms that include fungi and bacteria. Drying prevents germination.

1.2 Problem statement

In Kenya and other developing countries most farmers sun dry their grains since solar energy is freely available and works well except during rainy and cloudy conditions hence resulting to high post-harvest losses. When drying during wet season, the value of the grains can fall by between 5% to

58% unless sold to wholesalers with mechanical drying facilities at a discounted price (Mendoza and Quitco, 1984). Delayed drying leads cause grain discoloration, chalky kernels hence resulting to decreased yields. De Padua (2007) highlighted that one of the key causes of the poor quality of milled rice produced is the lack of drying capacity, particularly for the wet-season harvest.

Though there have been strides in technology development of flatbed dryers, their main problem is non-uniformity in final moisture of the dried paddy (Phan, 2003.). According to Hashemi (2007) rice is hygroscopic in nature as it gains moisture very fast from the surrounding environment. Therefore, when drying paddy using flatbed dryers it results in a high moisture gradient or non-uniform final moisture content. This is because in a flatbed dryer the air surrounding material grain is moist and there is a tendency of the paddy absorbing the moisture hence causing the non-uniform final moisture contents between the top and bottom of the drying bed. In addressing the problem of non-uniformity drying, incorporation of air reversal is necessary although it is labor intensive and costly in operating. Therefore, in this project we intend to investigate the effect of air reversal in reducing the final moisture content differential.

1.3 Justification

In order to retain the nutritional value paddy crop that is harvested, there is need to adopt the use of mechanical dryers, especially during wet and cloudy when use of the sun drying is not practically possible. However, some conventional mechanical dryers with kerosene burners as heat source, have been applied in the past, they normally use around 10–15 liters of kerosene to dry each ton of paddy (Gummert, 2007). The application of these dryers emits high GHG, and also are costly due to the steady increase on the price of kerosene. Rice husks which is cheaply available and in abundance can easily substitute these fuels.

The use of rice husks waste for paddy drying is very attractive considering that it is freely available because is generated at the rice mills where and can be utilized for drying hence reducing on the transportation costs. In most of the time some of the waste is utilized at farm level for mulching, but most of it is dumped on the road side or openly burnt in the fields. According to Waswa *et al*. (2002) it is noted that out of the rice paddy supplied to the stores, however, about 20% is recovered as rice husk and with an annual production of paddy in Kenya of between 45,000 MT to 80,000 MT, then the husks generated annually is about 9,000 to 16,000 MT.

According to Hashemi *et al.* (2009) to reduce energy consumption and the drying time, the temperature distribution from one layer to another must be fast and uniform with minimum difference; But if the difference of moisture content (MC) gradient between layers will be very high it will result in grain breakage. By using of exhaust fan the temperature and moisture distribution in the paddy layers become almost uniform. This is an advantage of exhaust fan and can accordingly provide more economic energy utilization and will provide premium quality, with high values of head-rice yield and whiteness

It should be noted that at times the harvesting of rice normally coincides with the wet period this is because in Kenya most of the paddy rice is grown under irrigation hence the growing of rice does not necessarily to be done at the onset of rains. Under these conditions sun drying will not be effective as it will result to high post-harvest losses.

From the World Bank report (2011) on the Missing food in Sub Saharan Africa (SSA), it is noted that the search for cost-effective drying technologies needs to be some of the main objectives for the current and future applied research efforts. This justifies the reason for adoption and adaptation of driers using cheap biomass fuel in order to reduce post-harvest losses.

4 1.Objectives

1.4.1 Main objectives

To develop and evaluate the performance of a rice husk fueled paddy drier.

1.4.2 Specific objectives

1. To establish paddy drying practices in Mwea Irrigation Scheme Kenya.

2. To design and fabricate a suitable drier for use in major rice production areas in Kenya.

3. To evaluate the performance and the drying characteristics of the dryer.

4. To carry out an economic evaluation of the drying equipment developed

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

One of the ancient practices used in grain drying is natural drying method in which the grains are exposed to sunshine and wind in an open ground or in the field. Artificial dryers however employ the use of heat derived from burning of fossil fuels and biomass resources directly or indirectly while using electric power to pump air through the grains via electric fans.

According to Phan (2003), flatbed dryer has been widely used for paddy rice drying in Philippines using rice husks as a fuel. Though this dryer is effective, it has a problem of non-uniform drying resulting to non-uniform dried grains. It is against this background; it is necessary to encourage the adoption of biomass fuel propelled paddy drying systems in Kenya.

According to Proctor (1994), oil and gas are the main conventional fuels employed in heated-air dryers particularly for grain drying operations such as the batch-in-bin grain dryer Under favorable sunny conditions, traditional sun drying method is widely used for drying grains including paddy rice. However, when the rice crop is ready to be harvested it does not always coincide with the drying sunny drying conditions. With increased research to develop better yielding varieties, use of Irrigation technology and better farming technologies have made farmers realize increased yields and harvesting in rainy seasons hence demands good post-harvest practices that include use of better and improved drying technologies. The use of alternative and renewable energy technologies for crop drying is fast being adopted considering that innovative and low-cost combustion technologies are being developed while normal petroleum and oil fuel cost keeps rising. The main agricultural wastes that have been identified for use for energy utilization and development include Maize Cobs, rice husks, bagasse from sugar sisal waste, banana leaves and coffee husks (Karekezi and Kithyoma, 2006).

Agricultural processing is an activity which is performed to maintain or improve the quality or to change the form or characteristics of an agricultural product. The main purpose of agricultural processing is to minimize deterioration of the nutritive value for the paddy grain and reduce post-harvest losses of the paddy grain after harvest (Sahay and Singh, 2001).

2.2 Agricultural Residue Resource of Energy for Drying

Biomass is the third largest primary energy resource in the world, after coal and oil. In all its forms, biomass currently provides about 1250 million Tones Oil Equivalent which is about 14% of the world's annual energy consumption. In developing countries biomass is a major source of energy providing 35% of all the energy needs (Werther *et al.* 2000). The utilization of biomass to provide partial substitution of petroleum fuels has an advantage regarding global warming since the combustion of biomass has the potential of being CO_2 neutral. As plants grow they normally remove the CO_2 from the atmosphere to be utilized in photosynthesis. This is again released during combustion.

Biomass materials which have a high energy content include, agricultural wastes like straw, bagasse, coffee husks and rice husks and residues derived from forest-related activities. The residues include wood chips, sawdust and bark. Residues from agro forest-related activities which excludes wood fuel normally accounts for 65% of the biomass energy potential. On the other hand 33% comes from wastes obtained from agricultural crops (Karekezi and Kithiyoma(2005).

The generation of straw waste from crops like wheat, barley and oat is distributed evenly and uniformly world-wide, both in the developing and developed countries. The generation of rice husks, bagasse and coffee husks is predominantly found in the developing countries. Rice husks and straw are the most important agricultural wastes amounting to 43% of the total wastes. About 97% of the rice husks are produced in the developing countries. In 1997, China alone generated about 54 million tons of rice husks (Werther *et al.*, 2000).

In paddy drying it was observed that the use of rice husks from paddy as fuel is the most suitable. The options available for air heating for drying crops include using furnace where ambient air is mixed with the flue gases or indirect air heating furnace using heat exchanger where hot water or steam is passed through a heat exchanger. The direct furnace enjoys several economic advantages because the investment in the furnace investment is only half when comparing to an in direct furnace. The furnace maintenance is much easier and at much lower cost. The rice husk consumption is also half compared to an indirect furnace. All contributes to a much lower drying cost, from components of the furnace depreciation and fuel cost (Phan, 2009)

2.3 Drying Technologies and their Design Features

There are different methods of drying crops such as sun drying in the open, use of solar dryers, mechanical dryers and flatbed dryers (Proctor, 1994).

2.3.1 Open Sun Drying

This is an ancient practice of grain drying where the crop is spread in the open to dry. This exposes the grain to the effects of sun, wind and rain. Currently, sun drying of grain is still the most common method of drying in tropical developing countries (Kaaya, 2010). Even though it doesn’t require a lot of labor or any other inputs the field drying of the grain result to pest infestation, contamination and mold growth. It results to delay in land preparation for the next crop season and crop can be easily damaged by animals and theft. Drying in the field can be done in the field after harvest with the harvested crop being arranged in stacks. The crop is raised above the ground and exposed directly to the sun (Kaaya, 2010).

2.3.2 Solar Dryers

Solar food drying can be applied in many areas but how fast the food is dried is dependent on many other variables such as the amount of sun insolation and relative humidity. The duration of drying for solar dryers varies between 1 to 3 days depending on sun intensity, air speed, relative humidity and the type of food to be dried.

There are mainly three types of solar dryers as follows:

i) Hot Box Sun Dryers

In this the material product is heated by sun directly,

ii) The indirect or convection dryers

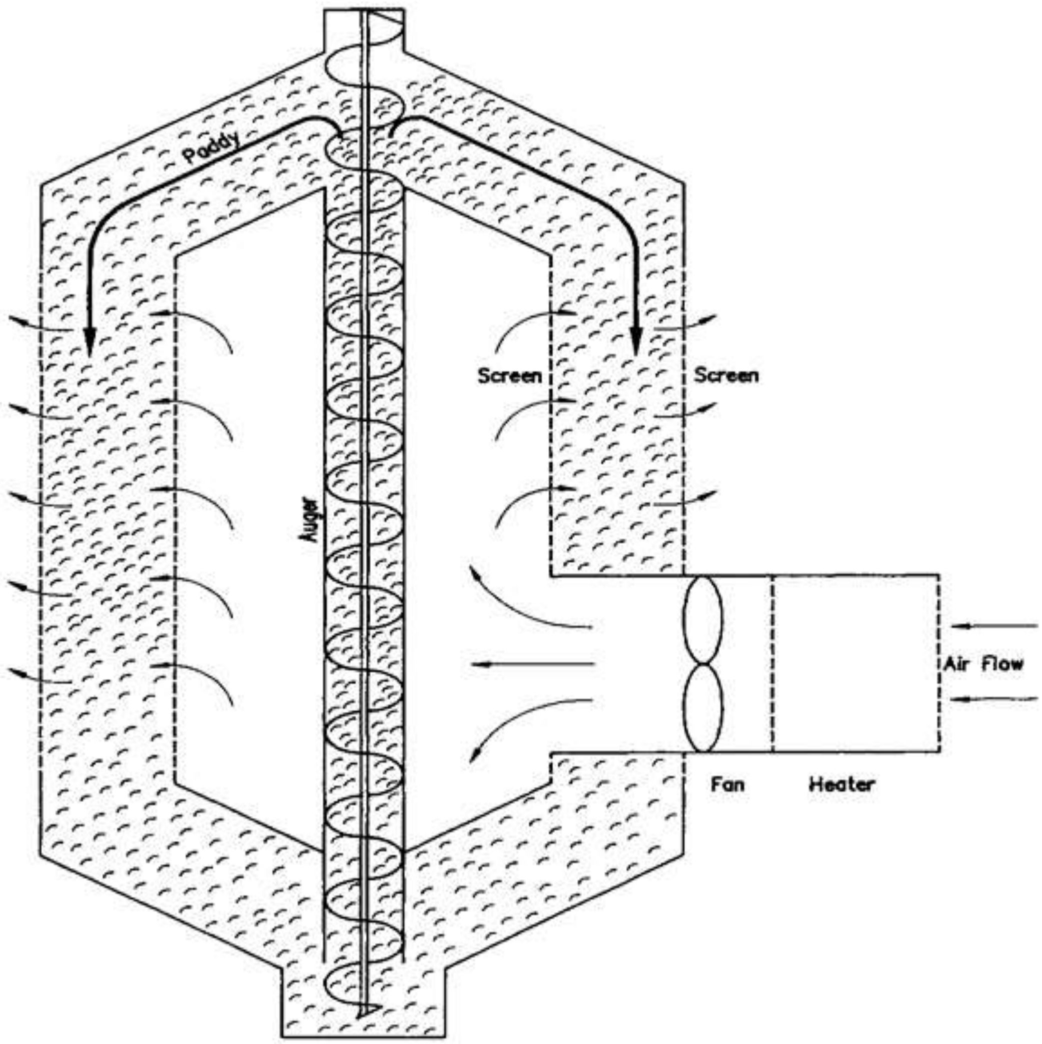
The drying material is exposed to hot air that has been heated by means of a heat exchanger. The convection dryers can further be divided to natural convection and forced convection where the heated air from the collector is forced and circulated using a blower. The natural convection types of solar dryers include solar tent dryers, cabinet solar dryers, greenhouse solar dryers.

iii) Hybrid Solar Dryers

Dryers applying the above two principles, in which material is exposed to the sun and a stream of pre-heated air at the same time (Fellows, 1997).

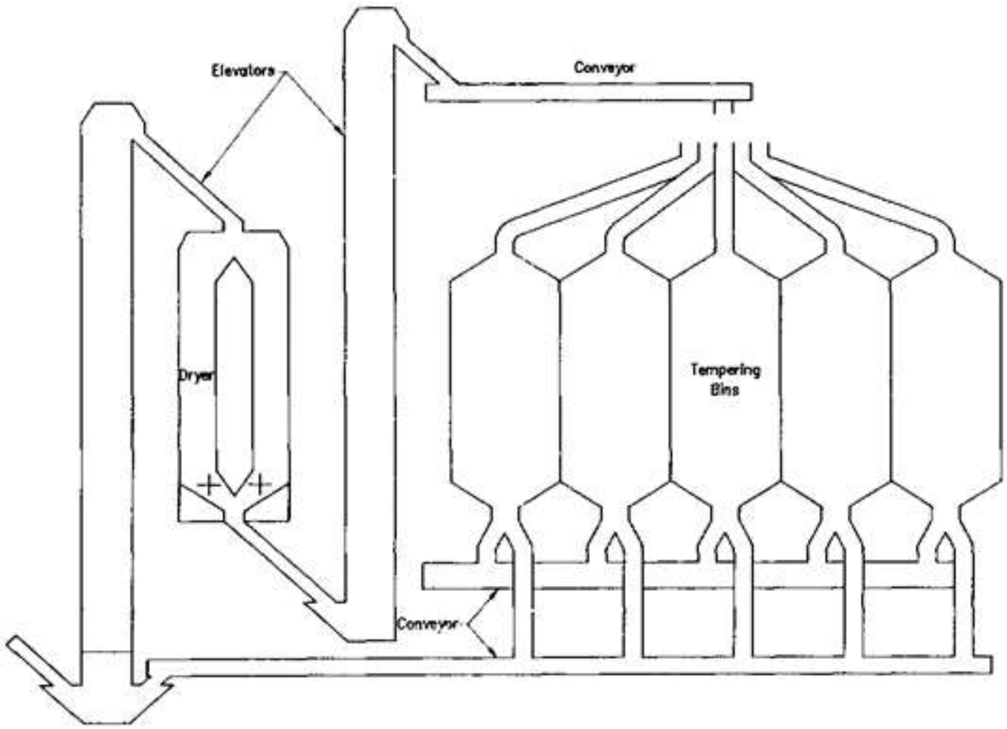
2.3.3 Mechanical Dryers

According to Proctor (1994) the main type of mechanical dryers are the recirculating batch dryer Fig 2.1 and the Continuous flow dryer as in Fig 2.2. These dryers are mostly used by large scale farms operations and companies since their initial cost are high.



Paddy
Screen
Screen
Auger
Air Flow
Fan
Heater

Figure 2.1: Recirculating Batch Dryer



Source: Wimberley (1983).

Figure 2.2: Continuous flow dryer

2.3.4 Flat Bed Dryers

According to De Padua, (2008) a flatbed dryer was first developed in the 1960's by the University of Philippines Los Banos (UPLB) engineers. This is the earliest and simplest commercial drying technology. The flatbed dryer, became the basis of developing all other dryers in the ASEAN, IRRI and Vietnam.

A flat bed dryer is generally a perforated mesh floor above a plenum chamber in which the grain to be dried is placed about one foot deep. The loading and unloading of the grain from the drying bed is done manually. Air which has been heated is pumped through the grain mass from below the plenum bed. The energy source used for heating can either be fossil fuel or biomass waste. Due to the increasing fossil fuel costs, systems adopted to use rice husks have been developed. Examples of the main types of flatbed dryers developed utilizing biomass include the SHG Model Fig. 2.3 and the University of Philippines Los Banos UPLB flatbed, Fig. 2.4

Figure 2.3: SHG Flat Bed Dryer

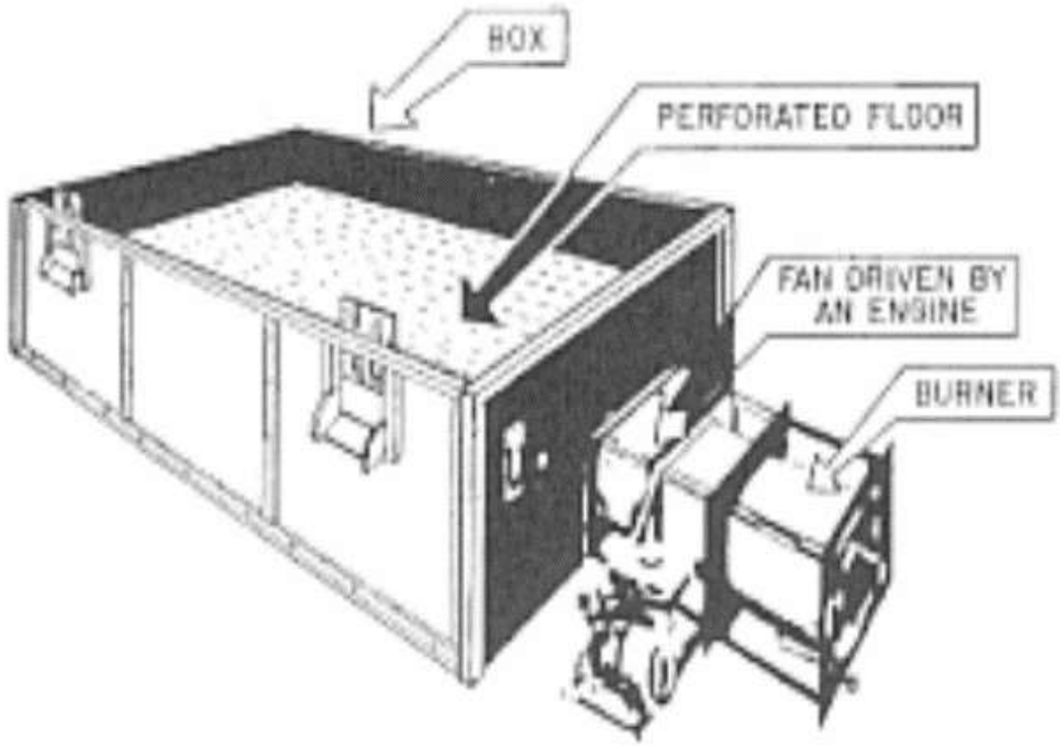


Figure 2.4: UPLB Flatbed Drier IRRI.

2.3.5 Advantages and Disadvantages of Paddy Drying Technologies.

According to Gummert (2007), it should be known that there is no ideal dryer for paddy rice drying .Each of the drying methods is characterized by inherent advantages and disadvantages which are summarized below;

Table 2.1 Summary of Drying Technologies

Method	Crop Flow	Drying Technology	Advantages	Disadvantages
Field drying		Piles, racks	Loosens the paddy grain in the panicle for manual threshing	Rapid quality deterioration
Sun drying	Batch	Drying pavements or mats	Cheap	Not cheap Typically poor milling quality
Heated air drying	Batch	Fixed bed dryer Example: Flatbed dryer	Inexpensive, small scale operation possible Construction using the locally available materials Can be operated with unskilled labor	Moisture gradient Not Inexpensive
		Re-circulating batch dryer	Mixing of grain Has big capacity range Good quality	Skilled laborers required The capital investment is moderate. Requires after-sales service The moving components wear.
	Continuous	Continuous flow dryer	Large capacity Economics of scale	High capital investment Use with small batches of different varieties is not feasible. Complicated
In-Store Drying	Batch	Storage bin with aeration components and pre-heater	Excellent grain quality	Pre-drying of high moisture grain

		for adverse weather and nighttime	Large capacity range	Risk of spoilage during power failure

(Gummert,2007)

From the summary of advantages and disadvantages, it shows that fixed bed dryers are the most suitable for adoption by small scale farmers since they do not require highly skilled personnel for operation. The dryers can be manufactured using materials available locally. They are cheap to fabricate and low in operational cost in terms of labor and fuel since they use biomass wastes.

2.4 Drying Performance

In assessing the drying performance, the drying mechanism, drying efficiency and effect of drying on the quality of the paddy grain material are discussed in this section.

2.4.1 Drying Mechanism

Drying as part of post-harvest process, is the reduction of moisture to safe moisture content of 12 to14% on wet basis (wwb) by the utilization of heat (Bala, 1997). Drying is practiced to retain the nutritive value of grain during storage to prevent the growth of bacteria and fungi and the infestation by other pests. Therefore drying is the method applied to condition the material by reducing moisture content to such a level that it is at equilibrium with the normal atmospheric air in order to preserve the nutritive value of the food product.

Grain drying refers to the reduction of the moisture from grain by mechanically moving air within the grain after it is harvested (Wehrspann, 1998). When the harvest is delayed the conditions become less favorable for grain to dry to match moisture contents considered safe for storage.

Paddy rice is hygroscopic in nature. It is a respiring living biological product. It will absorb and give out moisture depending upon the paddy moisture content (M.C.), air relative humidity (RH) and temperature conditions of the surrounding atmosphere (Lantin, 2006). As a living biological material the paddy's rate of respiration increases with the increase of moisture content.

Paddy respiration is manifested by a decrease in dry matter weight, utilization of oxygen, evolution of carbon dioxide and the release of energy in the form of heat. Respiration is negligible at moisture content of about l2-l4 % which is considered safe for storage (Lantin, 2006).

Paddy is usually harvested at moisture content of about 24-26 %(wet basis) which is higher during the rainy season and lower during the dry season (Lantin, 2006). At high moisture content during harvest, paddy has a high respiration rate and is very susceptible to attack by micro-organisms, insects and pests. The heat evolved during the respiration process is retained in the grain and in the bulk because of the insulating effect of the rice husk. The heat increases the temperature of the grain resulting in increased mould growth, fungi, insect and pest infection, which increases the quantitative loss and qualitative deterioration (Bala, 1997).

Grains become moldy yellowish and are infested by pests. Newly harvested grain which has a high moisture content must therefore be dried within 24 hours to about l4 percent (wwb) for safe storage and milling. When the moisture content is less than 14 percent, wet basis the paddy rice will not be easily attacked by fungal infections and its potential for germination is retained. In this way the shelf life of the grain will be longer and its nutritive value is retained. Wet grain has a high vapor pressure because it has very high levels of moisture content. When this grain is subjected to an atmosphere where vapor it pressure is very low, vapor transfer movement will occur from high to low until such a point that it the same or the paddy grain is in equilibrium with the atmosphere.

Drying therefore is subjecting the material to an atmosphere of low vapor pressure and providing the necessary heat to vaporize and remove the water evaporated from the grain (Lantin, 2006). The same is true of moisture movement in the grain material. Moisture movement from the center of the grain to the surface occurs at the time of drying to the point that the moisture has been distributed evenly within the grain. Therefore, in the process of drying using the sun the grain is heated by sun’s heat hence removing the water and the air movement around the grain material pushes away the moisture evaporated from the grain.

In the process of drying heat is necessary for removing water from the grain and movement of air is required to carry away the moisture that has been evaporated. According to Wimberley (1983) there are two basic mechanisms that take place in the process of drying; the migration of water from the interior of an individual paddy grain material to its surface, and the follow evaporation process of moisture movement from the grain surface to the air surrounding it. The speed of drying depends on the moisture content amount, the temperature of the grain, relative humidity and the speed flow of the surrounding air. From the studies done Gummert (2007) it is observed that the temperature range for paddy drying is 43 ºC-48 ºC.

2.4.2 Drying Efficiency

The efficiency of the dryer is one of the main factors used in assessing and selecting the optimum dryer for a specific task. According to Teter (1987) there are several different ways of expressing the efficiency of drying, of which the Sensible Heat Utilization Efficiency (SHUE), the fuel efficiency, and the dryer efficiency are the most useful.

The fuel efficiency is computed from the heat due from the fuel. It is given by Equation 1 (Teter, 1987)

$$\text{Fuel Efficiency} = \frac{\text{heat utilized for moisture removal}}{\text{heat supplied from fuel}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..1$$

The fuel efficiency will be greatly different for the use of the same dryer at different locations with different ambient conditions. With the drying in low temperature region, the heat used from the fuel may be less than half of the total sensible heat and the fuel efficiency can be more than 100%. This is not possible to compare directly the fuel efficiency performance at another area.

The drying efficiency, is obtained from Equation 2 (Teter,1987)

Drying efficiency

$$= \frac{\text{heat utilized for moisture removal}}{\text{heat available for moisture removal}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .2$$

2.4.3 Effect of Drying on the Grain Material Quality

The drying process does not only involve moisture removal but it can degrade nutritive value of grain if the right drier is not used. The requirements of high-quality grains include; low and uniform moisture content, minimal proportion of broken and damaged grains, low susceptibility to subsequent breakage, high viability, low mold counts; high nutritional value, consumer acceptability of appearance and organoleptic properties (Brook, 1981).

2.5 Economic Analysis of Dryer

Economic analysis of a dryer is informed by the cost of design and fabrication besides the benefits. According to Swain *et.al* (2014) the costs to be considered in doing the economic analysis are the capital cost, variable cost, and fixed cost. The variable costs to be considered include the cost of energy and labor. The fixed costs are depreciation, interest on investment, insurance and maintenance costs. The various economic indicators considered in this study while doing the analysis include Benefits Cost ratio, payback period and rate of return on investment.

Chayan *et.al* (2017) undertook an assessment of BAU-STR dryer using briquettes as fuel, it was found out that dyer payback period was below one year. Regarding the cost benefit ratio, for the one operating using diesel it was 1.91 and for that using electrical energy was 2.35.

Dhanushkodi *et.al*(2015) conducted a viability assessment for substituting biomass, solar, and hybrid dryer in place of using steam to dry cashewnuts. From the feasibility done it was reported that the solar powered had a payback period of 1.58 yrs and for the hybrid drying it was 1.99 yrs. The computations for cost-benefit was 5.23 for solar and 4.15 for biomass and 3.32 for the hybrid dryer.

2.6 Emissions of Biomass Combustion

Aneta *et.al(*2011) notes that the utilization of the biomass wastes in combustion systems because has very low emissions of NO_X, SO_X and CO_2. Using biomass as fuel in existing coal fired plants is taken to be as a significant effort in reducing environmental emissions given that it is assumed to be CO2 neutral.

Due to increasing levels of environmental pollution most governments have legislations that guide on the required appropriate emission levels from combustion equipment. In Kenya the government has developed the Air Quality Regulations 2014 that was enforced from 2017 by National Environmental Management Authority (NEMA).The regulations provide that emissions from combustion equipment must be measured on yearly basis and the report submitted to NEMA.

Considering that paddy is covered by a husk which is removed when milling, then the utilization of flue gases directly will not affect the quality of the milled rice. Phan (2009) notes that flue gas with a concentration of (0.7%) does not affect the grain quality. Of this 0.7%, about 8-12% are CO_2 (carbon dioxide) and 0.1- 0.5% are CO (Carbon monoxide) thus are too small to constitute an environmental threat. Also other carcinogenic (cancer-causing) substances are non-existent in biomass combustion.

2.7 Summary of Literature Findings

Assessing the reviewed literature, it shows that rice production in the country is lower than the demand hence there is need to address reduction of post-harvest losses that are incurred hence preserving what is currently produced. It should be observed that paddy drying is one of the main problems that cause post-harvest losses. From literature review it shows that there are abundant agricultural wastes which include rice husks for use as fuel for drying activities since the price of furnace oil is high hence increasing the farmer's costs. It is noted also that the use of biomass waste has low emissions of NOX, SOX and CO_2 compared to the expensive fossil fuels.

It was found out that the main challenges in the use of agricultural wastes as a drying fuel is that it generates a lot of ash content and its melting point is low. Ash causes the fouling of the burner systems and the heat exchangers and results to reduced performance of the system and high cost of maintenance. Hence there is need to choose a system that is capable in reducing these challenges. Also the other challenge of agricultural wastes is its low bulk density. This increases the cost for transporting if it is to be utilized away from the production site. Thus using the waste generated in drying the crop at the site makes economic sense as it reduces transportation costs.

The lessons learnt are that the mechanical dryers though effective, have high operational costs since they use furnace oil and need highly skilled operators. Also sun drying though very cheap, is dependent on the availability of the sun but when cloudy and raining the drying cannot be rapidly achieved and hence results to post harvest losses.

Thus the cheap system that can easily be adopted by farmers as it doesn't need highly specialized skills is a simple flatbed drying using paddy rice husks as a drying fuel. The problem with flatbed dryers is the non-uniform drying of grains between the top and bottom of the bed. This requires manual turning of the grains for the achievement of uniform final moisture content. From laboratory studies by some researchers it has been established that adding an exhaust fan at the top of the grain bed tend to achieve a uniform moisture content. For the study it used a combustion furnace system for paddy drying process via generated flue gases to heat the cold air directly. The hot air was applied through the plenum chamber of dryer bed for paddy drying. A fan sucked the hot flue gases which mixed with ambient air to the plenum chamber and then forced through the grain to achieve drying process by extracting moisture, and this air is discharged by an exhaust fan. The use of the direct combustion is cheaper than the use of heat exchangers and gasifiers for drying process.

CHAPTER THREE

METHODOLOGY

3.1 Research Design

The research involved undertaking field survey in Mwea Irrigation Scheme to establish drying practices and waste generation. From the data collected a model flatbed dryer was designed and fabricated and performance testing done at the Kenya Industrial Research and Development Institute (KIRDI) workshops.

3.2 Field Survey Procedure

The selected site for field survey was Mwea Tabere Scheme which is located 100 km North East of Nairobi city with Latitude of 0^o 45' 55" S and Longitude of 37^o 21' 14" E. The survey covered randomly selected 300 farmers from a population of 3000 farmers representing 10% of population as per Mugenda and Mugenda (2003). The survey was conducted using semi-structured questionnaires (Appendix I). Also surveyed include all the 20 rice millers in the areas surveyed. The millers interviewed composed of 20% large mills and 80% small mills. Piloting of the questioners was done using the enumerators and the questionnaires were corrected accordingly. The analysis of the questionnaires was done using SPPS Version 7 and Excel Package from which detailed descriptive statistics was generated.

3.3 Design of the Drying System

A prototype biomass flatbed dryer as shown in Fig 3.2 was designed and fabricated at Kenya Industrial Research and Development Institute (KIRDI). The system components fabricated included combustion furnace for supplying hot air to 250 kg capacity flatbed drying bin. In operation, rice husk was fired in the combustion chamber and hot air was sucked by a centrifugal fan thereby mixing it with ambient air and directed to the plenum drying chamber enhancing drying via heat and mass transfer process with residual air exiting through the bed top. In order to enhance efficiency, the system was modified to incorporate an exhaust fan to extract exiting humid air as shown in Fig 3.2. Detailed design procedure for the dryer is given in section 3.2.1.

The following design procedure was applied in the design of the paddy drying system.

The conditions and assumptions made are summarized on Table 3.1. The design conditions used included paddy crop characteristics, climatic data from Mwea Irrigation and Development Centre (MIAD) weather station, dryer capacity, Initial and final moisture content and drying duration. The total moisture loss required for 250kg batch in order to reduce the moisture content from 26% to 12% (wwb) was used to determine drying system design parameters. The initial paddy moisture content of 26% (wwb) as obtained from the field survey. The final moisture content is for safe storage is 12% (wb) as per Gummert, 2007).

3.3.2 Sizing of the Dryer

The size of the prototype industrial dryer was established as a function of the drying area required per kilogram of paddy grain. The drying temperature was established as a function of the maximum limit of temperature the grain might support. From the climatic data derived from field study area (Mwea Irrigation Scheme): the average day temperature for September to December was 23 ºC while average relative humidity was 70% (RH). This gave a humidity ratio of 0.016kg_wv/kg_a as derived from the psychometric chart. The maximum allowable drying temperature of paddy grain without changing the nutritive value was maintained at 45 ºC and below (Gummert, 2007). The final moisture content of dried paddy rice for safe storage was assumed to be 12% wet basis (Gummert, 2007).In sizing the drying system, the Energy balance equation was used as per Ezekoye *et al*. (2006).

Energy Balance Equation used in the Drying Process

$$M_w L_V = M_a C_p (T_1 - T_2) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 3$$

Where $T_1 = 23^oC$ (Ambient Temperature, ^oC),T_2 is drying temperature at (45^oC))

T_1 and T_2 = initial and final temperatures for the drying air respectively (K).

M_w = Mass of moisture evaporated from the food item (kg);

L_v = Latent heat of Vaporization of Water (kJ $kg^{-1}K^{-1}$).

M_a= mass of drying air (kg)

C_p=Specific heat capacity of air at constant pressure ($kJkg^{-1}K^{-1}$

Table 3.1 Design Specifications and Assumptions

No	Parameter	Condition and assumption	References Cited
1	Location	MweaTabere Irrigation Scheme (Latitude)	Field Survey data obtained in Mwea Tabere
2	Crop	Paddy Rice	Obtained in Mwea Tabere
3	Crop Porosity (ꜫ)	0.42	Gummert (2007)
4	Bulk density for paddy ø(kg/m)	850	Gummert (2007)
5	Loading bed void fraction (εv)	0.48	Gummert (2007)
6	Drying period (hrs)	4	Fixed at Laboratory from data from Mwea
7	Drying per batch(kg)	250	Fixed at Laboratory from data from Mwea
8	Initial moisture content, Mi [%]w.b	26	(Nathan *et al.*, 2015)
9	Final moisture content, Mf [%]w.b	12	(Nathan *et al.*, 2015)
10	Ambient air temperature, T_{am} [^oC]	23	Data from MIAD
11	Ambient relative humidity, RH_{am} [%]	70%	Data from MIAD
12	Maximum allowable temperature, T_{max} [^oC]	45	Gummert (2007)
13	Calorific value of rice husks as determined by Bomb calorimeter(kJ/kg)	13200	Determined at KIRDI Laboratory Service Centre (LSC)
14	Moisture content of rice husks wb (determined)%	6	KIRDI Laboratory Service Centre(LSC)
15	Design parameter of rice husks(D_h)	560,000-1,120,000	(Singh *et al.*,1989)

3.3.2.1. Moisture loss

The amount of moisture to be removed from the products was computed using the formula given by Ichsani and Dyah (2002) as below:

$$M_w = \frac{m_i(M_j - M_e)}{100 - M_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

The paddy rice has a moisture content of 26% after harvest and it is to be dried to 12 % (wb)

M_{w} = Moisture evaporated

m_{i}=Initial weight of the product

M_j =Initial moisture content of product

Me=Final moisture content of product

Then; Mw =250 (26-12)/100-26=47.3 kg

3.3.2.2 Quantity of Air needed for Paddy Drying

The amount of air required for drying can be computed from the energy balance equation for drying process (Ichsani and Dyah, 2002) as:

$$maCpa(T_A - T_B) = M_W L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

The amount of air can be computed by idealizing the process of drying on the psychometric chart. If ambient air at temperature T_A (23^{o}C) and relative humidity RH_A (70%) is heated to temperature T_B (45^{o}C), then RH_A will reduce to RH_B. This heated air is used to remove water, M_w (47.3kg) from the paddy rice of mass m_i (250kg) until equilibrium Relative Humidity is reached. The temperature of drying air will reduce from T_B to T_C and the humidity ratio; will increase from W_B to W_C with increment of

$\Delta W_{CB} = (W_C – W_B)$.$\Delta W_{CB} = (W_C - W_B)$ …………………………………………….. 6

The quantity of air needed to drive moisture in the drying process is given by (Ichsani and Dyah, 2010) as:

$$m_a = \frac{M_w}{\Delta W_{CB} \text{ x n}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .7$$

Where; m_a is the quantity of air required to remove moisture from the product; Mw is the amount of moisture to be removed; ΔW_{CB} is change in humidity ratio that is the water that can be driven off by the heated air; and n is the pickup factor.

According to Axtell (2002) a perfect transfer of moisture is not practically possible in drying of the food and biological materials and therefore in designing dryers for these products a pick up factor was introduced. This pick up factor takes into consideration the type of the food and biological materials being dried and the ease with which it releases moisture to the air. Hence, the actual amount of water that would be driven from the products per kg of drying air can be determined.

Given that from the psychometric chart Fig 3.1 (at ambient temperature and relative humidity of 23 ^{O}C and 70% respectively), W_B = 0.016 kg/kg dry air and W_C = 0.0236 kg/kg dry air, hence, ΔW_{CB} = 0.076 kg/kg/dry air. Therefore, using a pickup factor of 0.25 and substituting M_w =47.3 kg and ΔW_{CB} = 0.0019 kg/kg dry air into Equation 3 resulted in Ma = 9957.9 kg. Since we need to dry with in a period of 5 hr per batch, hence, m_a= 1991.5kg/h or 0.553kg/s.

Therefore, the mass flow rate to be driven out from the paddy rice per unit time is 0.553kg/s.

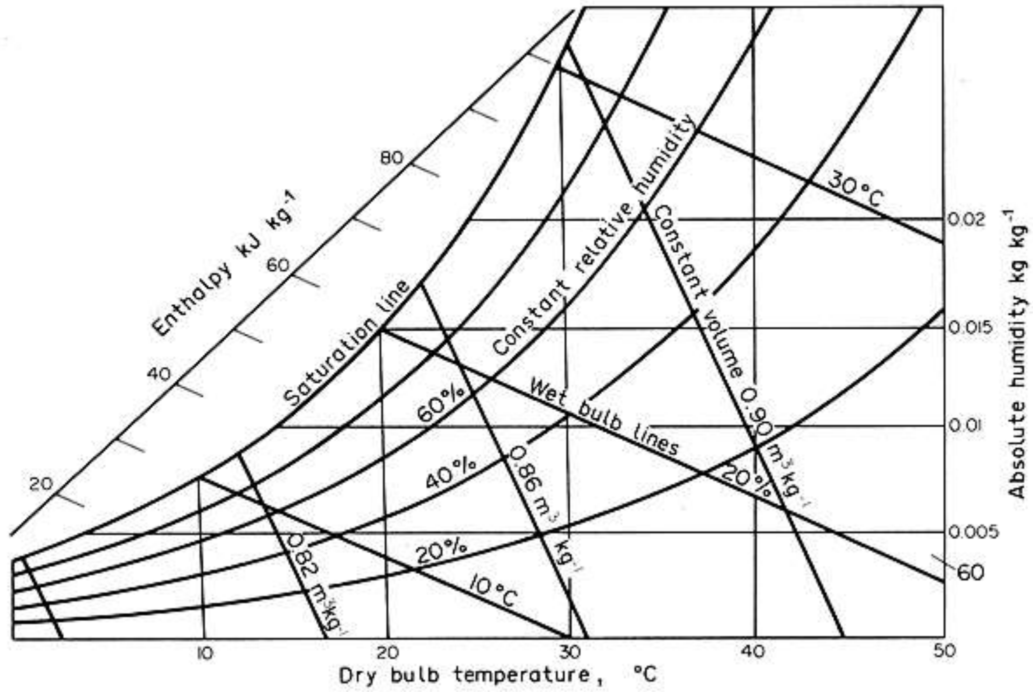


Figure 3.1: Pyschrometric Chart

3.3.2.3. Design and Selection of Fan

The fan size was determined by computing the volumetric flow rate of the air for drying which was given by Axtell (2002) as:

$$M_V = m_a \text{ x } v_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8$$

Mv –Volumetric flow rate of the air in m^3/s and Vs specific volume.

Substituting v = 0.871 m3/kg (from psychometric chart) and ma= 0.553kg/s (from Equation 8), hence,

m=1734.6m^3/h or 0.45 m ^{3}/s. Therefore, a 1hp centrifugal fan of speed 0. 45m^3 /s was selected for the dryer.

3.3.2.4 Sizing Paddy Drying Chamber

In order to size the dryer we must first know the drying area required.This will be established by the Equation 9 (Tonui *et al.* 2014)

$$A = \frac{W_w}{\rho_{gr} h_L \xi (1-\varepsilon_v)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

The amount of paddy W_w needed drying is 250 kg

Bulk Density (ρgr) of the wet paddy 25%-26%M_C=850 kg/m^3

Crop porosity (ξ) = 0.42

Load bed Void (ε_v) = 0.48

Substituting the values into equation 9, the drying area A =4 m^2

To calculate the length (L_{db}) of the drying bed, the breadth of the drying chamber B was fixed at 1.6 m for ease of sampling and the drying bed depth at 0.4 meters since the maximum depth to dry was 0.3 m. Thus, the length of the dryer bed L_{db}, was determined using equation 10 (Tonui *et al.*, 2014)

$$L_{db} = \frac{A}{B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . 10$$

Hence substituting in the equation to to the length; the length of drying bed is about

L = 2.5 m

Hence the dryer bed dimensions of 2.5 m x 1.6 m x 0.4 m were obtained.

3.3.2.5. Energy Requirements for Paddy Drying

The amount of heat required from rice husks to dry was determined using Equation 11 as given by Axtell (2002).

$$Q = m_a (H_2 - H_1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..11$$

Where

H_1 and H_2 = Specific enthalpy in kJ/kg

Substituting for the values in equation 8 yields;

Air mass flow rate (m_a) =0.55kg/s

Using the Psychometric chart, with H_1 = 68.0 kJ/kg air; H_2 = 86 kJ/kg air; and m = 0.55 kg/s (from Equation 3), hence, Q = 8.1 kJ/s or 8.1 kW.

3.3.2.6. Sizing the Combustion Chamber

In sizing the furnace, calculate the amount of rice husks needed for combustion

The amount of rice husks needed to be burned in the combustion chamber was determined using Equation 12 (Singh *et al.*1980)

$$M_H = \frac{q}{C_v} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

Where M_H =Quantity of rice husks

Substituting the values in equation 12,

The energy required q =8.1 kJ/s

Calorific value of paddy rice husks Cv = 13200kJ/Kg.

Quantity of paddy rice husks M_H =1.8kg per hour with combustion efficiency of 70%

Husks required is = 2.6kg per hour.

Husks burning rate is 2.6 kg/h

3.3.2.7. Volume of the Combustion Chamber

The volume of the combustion chamber (V) was determined by use of equation 13 (Singh *et al.*1989)

$$V= BC_C/D_h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

Substitute the values in equation 13.

Feed rate or burning rate of paddy rice husks (B) = 2.6 kg/h

Higher heating value of rice husks (Cc) = 13,200kJ/kg

Design parameter of rice husks (Dh) = (560,000-1,120,000 kJ/h.m^3

On this basis of design calculations, the final design of the paddy dryer is shown in Figure 3.2

Volume = 0.53 m^3

Fixing the Diameter at 0.3m as per (Dhanushkod S., *et al* 2015), then the height of the Lower part of combustor is 0.25m.

3.4. Fabrication Procedure for the Paddy Dryer

The combustion chamber was fabricated using 1.5mm mild steel plate which was cut with a guillotine cutting machine and then welded to form the lower and top part. The pipe for exhausting hot gases from the burning of the rice husks was welded at the center of the combustor and coupled to a centrifugal fan. The drying bed was fabricated by use of the square tubes which were welded to form the stand and then welded and the coffee mesh was fixed on it to form the drying bed. The sides of the bed were covered using galvanized sheets which were fixed using pop riveting machine. The final design of the paddy dryer assembly is shown in Figure 3.2. The materials utilized in the fabrication of the dryer are shown in Table 3.2.

Table 3.2 Materials used for Fabrication of the Dryer

S/N	Material Description	Specifications	Quantity
1	Mild Steel Plate	2.4 m x1.2 mx1.5mm	1 pc
2	Galvanized iron sheets	8ft x 4 ft	3 pcs
3	Square tubes	25 mm x 55 mm	3 pcs
4	Weld mesh	2.4 m x1.2 m	1pc
5	Coffee mesh	1.5 m x 3 m	3 meters
6	Welding rods	1.5 mm	1 packet
7	Centrifugal fan	1 hp made in India	1 pc
8	Black pipe	50mm	2 meters

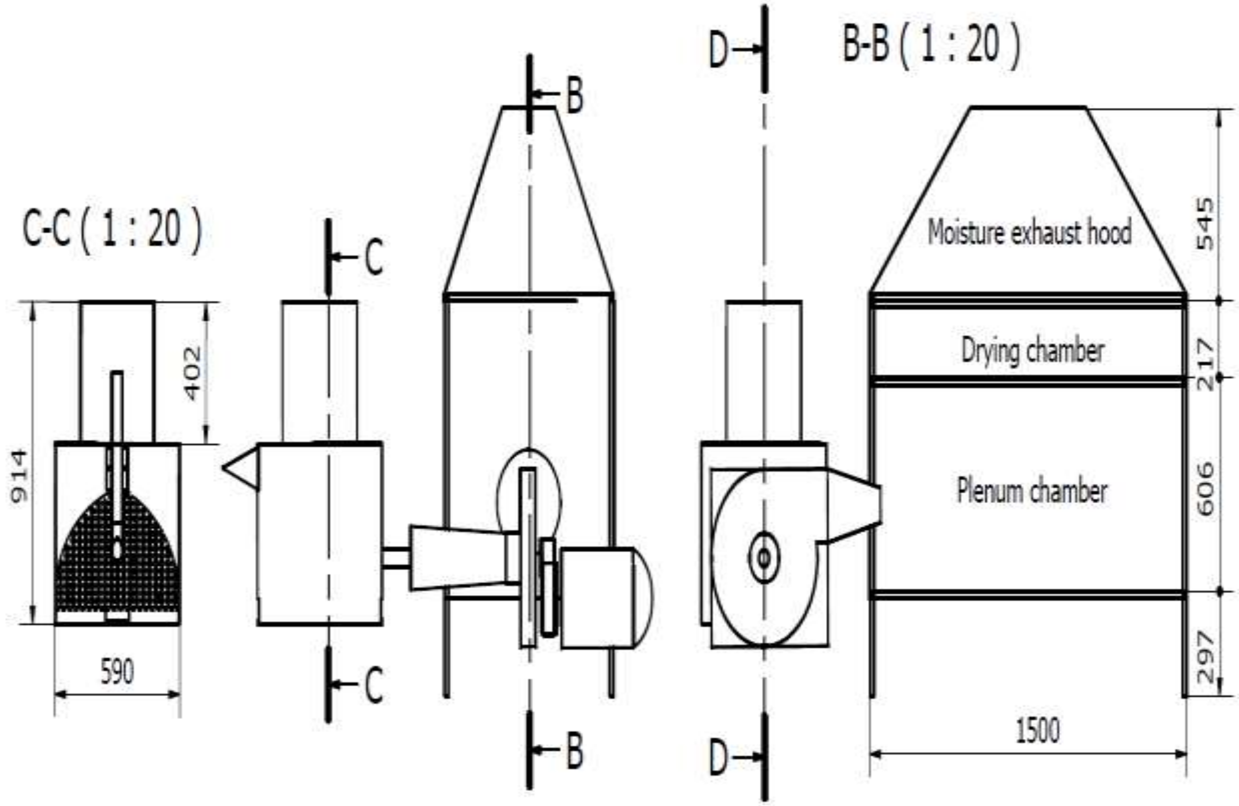


Figure 3.2: Engineering of Designed Paddy Drying System

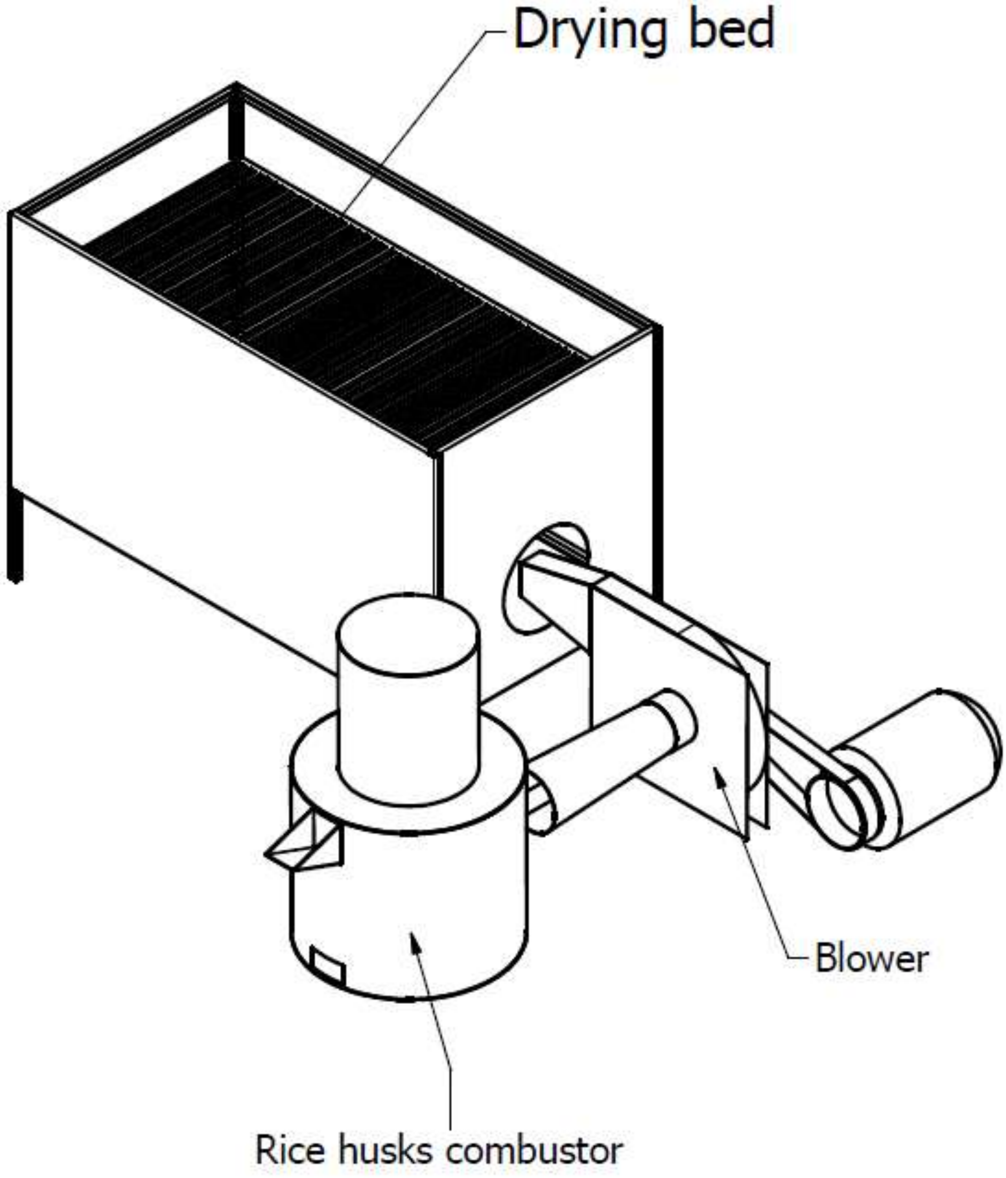


Figure 3.3 Diagonal View of the Paddy Dryer

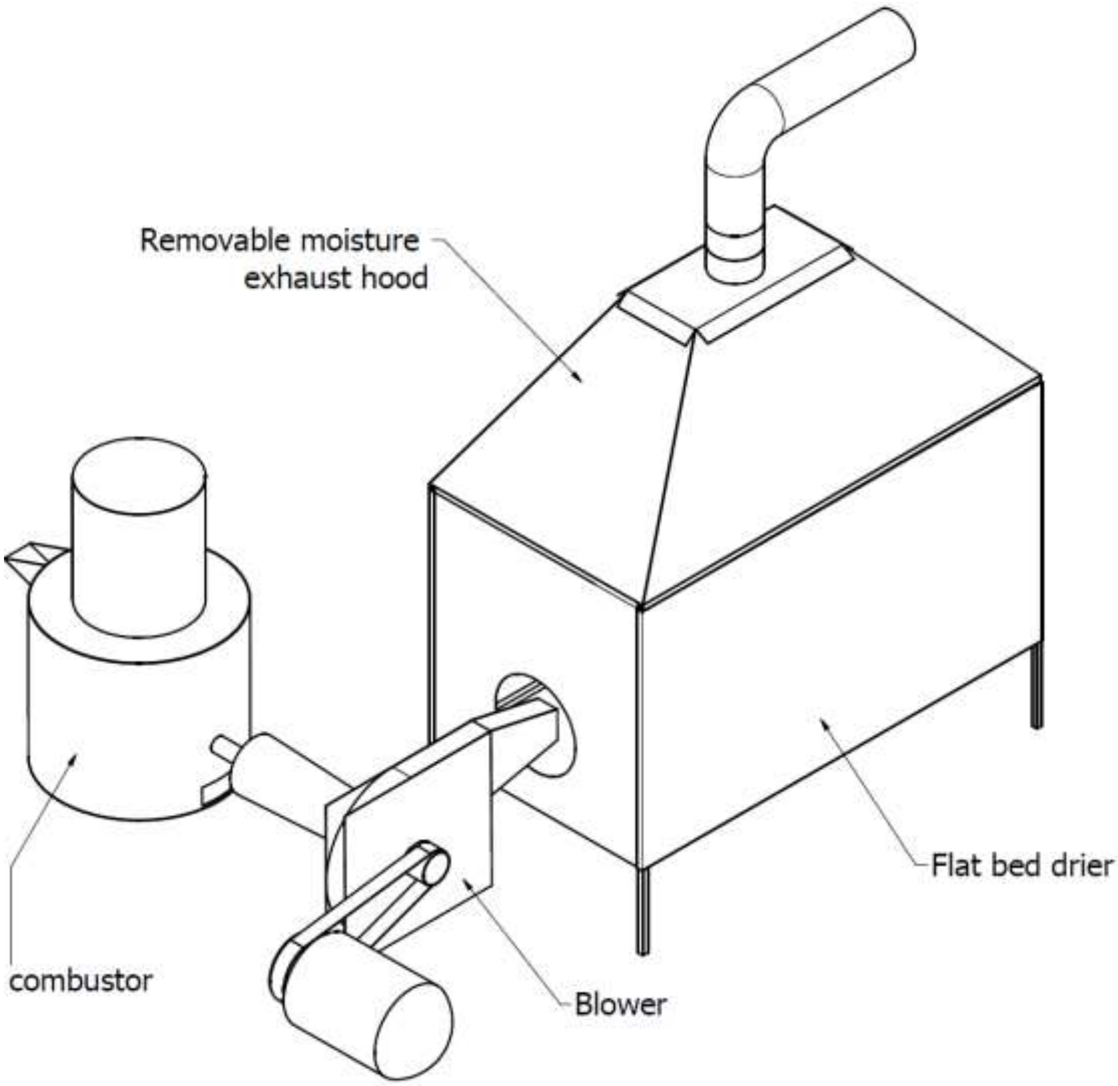


Figure 3.4 Paddy Drying System with the Exhaust Fan

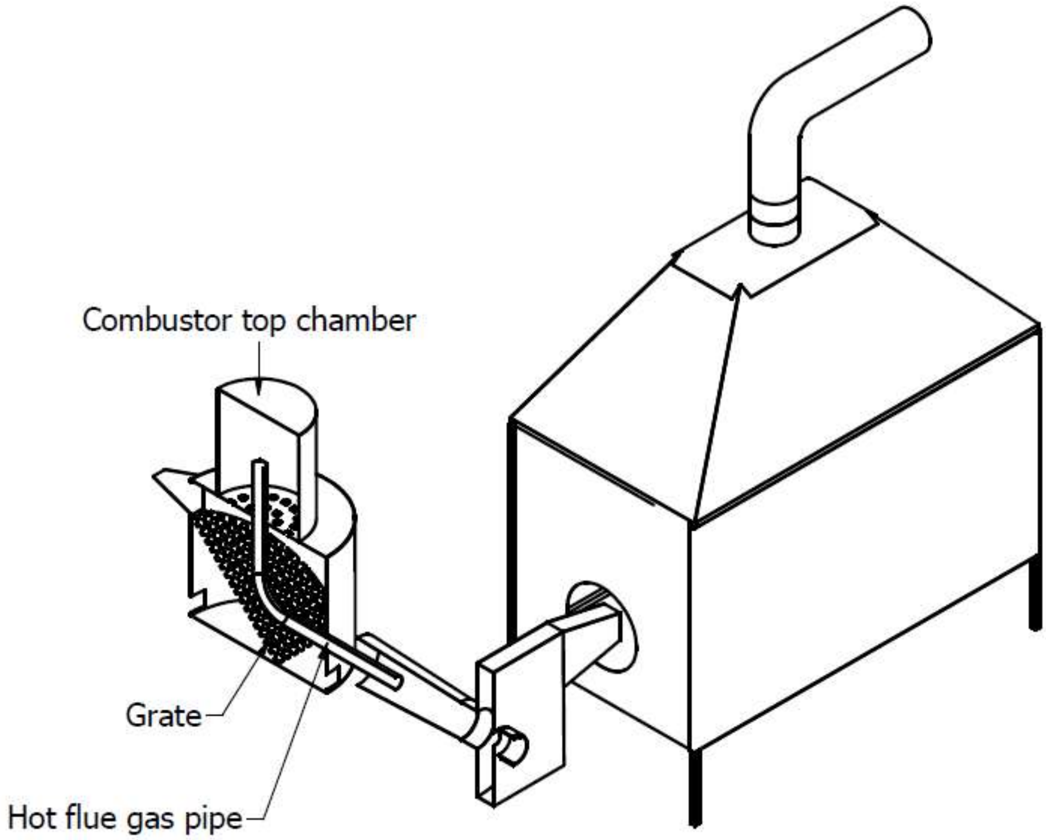


Figure 3.5 Combustor showing flue gas pipe and grate

3.5. Performance Testing Procedure for Paddy Drying System

Drying experiments using paddy rice were performed to determine the performance of the dryer with the exhaust fan and without the exhaust fan as per Heshami *et al.(*2009)

3.5.1 Instrumentation

The instruments used in collecting data for performance evaluation were:

a) **Weighing Scale**

Weighing scale made in India model was used for determining the weight of grain samples and determination of moisture loss in grains.

a) A portable grain moisture analyzer

Moisture analyzer model I-602 made in India was used to determine moisture content of paddy rice.

Drying Oven

Drying oven made in Germany model NO:B217 was used to determine moisture of the grains at 30 minutes' time intervals and for rice husks in the lab.

b) A multi-channel Testo Thermocouple

A multi-channel Testo model 735-2 thermocouple made in Germany, with temperature range

10 ^{o}C to 60 ^{o}C with accuracy of ±0.5 °C and a resolution of 0.15% was used for temperature measurements.

c) Hygrometer

Hygrometer Testo model 608H made in Germany with resolution of 0.1% was used for measurement of humidity of inlet and exiting air at 30 minutes' time interval over the drying period.

d) Air flow meter

Air flow meter model AM-4201 (India) with resolution of 0.01m^3/s was used for measurements of air flow rate through the dryer just behind the centrifugal fan.

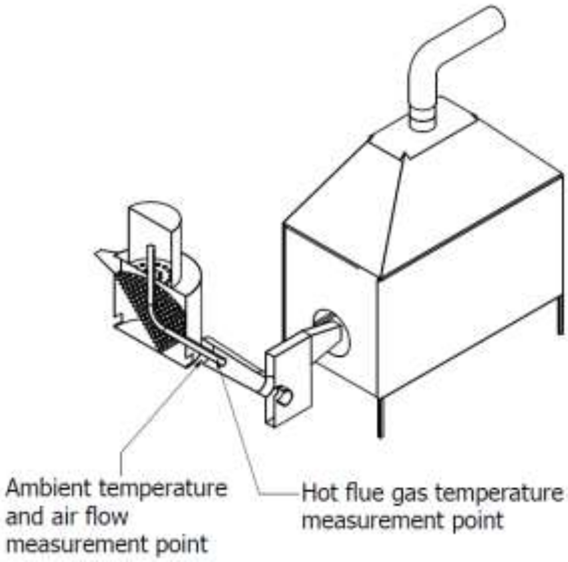


Figure 3.6: Locations for airflow flue gas and exhaust temperature measurements

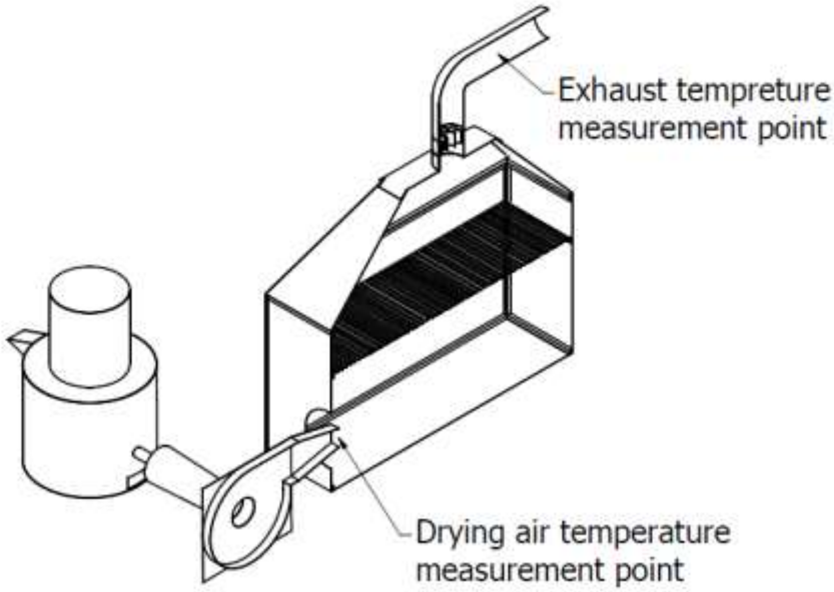


Figure 3.7: Locations for drying and exhaust temperatures measurements

3.5.2 Measurements and Drying Parameters Analysis

The parameters were analyzed as described below:

a) Temperature measurements

The temperature measurements were made in various locations by using Testo Model 625 made in Germany. Measured temperatures included ambient temperature, furnace combustion chamber temperature, the flue exhaust gas temperature, drying bed temperature, mixed ambient air and flue gases (drying air) temperature and the exhaust section temperature as shown in Figures 3.6 and 3.7. The temperature measurement recordings were done at 30 minutes' interval for duration of four hours.

b) Humidity measurements

The humidity was measured by using Testo hygrometer 6125 made in Germany; with an accuracy of ±2.5%. This was achieved by recording values of relative humidity in the room at thirty minutes' time interval over drying duration.

c) Airflow measurements

Airflow measurements were made using a vane anemometer Model AM-4201 (India) with accuracy of ±0.1m/s. The anemometer was used in determining the volume of air sucked by the centrifugal fan.

d) Thermo physical Properties of Paddy Rice and Biomass Rice Husks

Moisture content for the paddy samples collected from 300 paddy farmers and 20 millers were analyzed using a portable microprocessor grain moisture tester model I-602 made in India with an accuracy of ±0.7% and resolution of 0.1%.

Paddy rice husks thermo physical properties shown in Table 3.3 were analysed by the quantity of energy given out per unit mass or volume when the husk is burnt completely (calorific value, in MJ/kg). The calorific value of the rice husk material sample was evaluated experimentally as per ASTM D240 standard method by use a bomb calorimeter model: CAB001.AB1.C made in India available at the Lab Services Centre (LSC) of KIRDI. Loading of the samples of about 1 ± 0.01 g into the bomb calorimeter was made and allowed to burn in the presence of oxygen pressurized at 30 bar inside a sealed container (bomb calorimeter). The heat from the combustion of the husks was transferred to a mass of water that surrounded the chamber allowing the calorific value to be computed, as the product of the mass and specific heat of water and the rise temperature recorded. The computed calorific value was corrected to take in to consideration, heat loss as a result of conduction through the container wall to the surrounding of the equipment. In this experiments corrections were made automatically using sensors and controllers. The measured calorific value was taken as a gross value at constant volume because the biomass combustion in the container has taken place inside the fixed volume of the container (Jenkins *et al.*, 1999)

d) Measurement of moisture content.

The moisture content for the paddy grain and rice husks was measured using the Oven Method of drying at the KIRDI Laboratory Services Centre (LSC). In this experiment, about 20 grams of the sample was measured in a crucible and later put in an oven at a temperature of 108 ^{o}C for 24 hours. Knowing the final weight of the sample, the moisture content was established as per Jenkins *et al* (1998).

In sampling the grains for the moisture analysis, samples were drawn from the top and bottom part of the dryer and their moisture obtained separately. This was done for both the dryer with and without an exhaust fan.

Table 3.3 Methods of analysis of biomass rice husks

Property	**Reference Standard**	**Reference**
Particle size distribution	ASTM E828	Jenkins *et al*. (1999)
Bulk density	ASTM E873	Jenkins *et al*. (1999)
Proximate composition		
Moisture	ASTME871	Jenkins *et al*. (1999)
Ash	ASTME830 (575^{O}C)	Jenkins *et al*. (1999)

Heating value (Hv)	ASTM ABBE	Jenkins *et al*. (1999)
Volatiles	ASTM E872/E897	Jenkins *et al*. (1999)
Fixed Carbon	by difference	Jenkins *et al*. (1999)

3.6. Drying Performance Evaluation

The dryer performance parameter that is biomass heater efficiency, drying chamber efficiency and the overall system efficiency were determined.

a) Biomass heater efficiency

The biomass heater combustion efficiency η_h refers the ratio of useful heat gain over the product of fuel consumption and calorific value as in equation 14 Ezekoye *et al*., (2006)

$$\eta_h = \frac{m_a \, . Cp_a \, (T_o - T_i)}{C_v \, x Q_H} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 14$$

b) Drying chamber efficiency

Dryer efficiency is the ratio of difference between the dryer chamber inlet and outlet temperature to the difference between the drying chamber inlet and ambient temperature as shown in equation 15 (Ezekoye *et al*., 2006).

$$\eta_c = \frac{T_1 - T_2}{T_1 - T_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

c) Overall Drying Efficiency

System efficiency is the ratio of the energy required to evaporate the moisture to the energy given to the drier. It is an indicator for the overall effectiveness of a drying system, including biomass heater fig 3.8 and dryer chamber Fig 3.9. It can be expressed as

Overall Dryer Efficiency =Combustion efficiency x Drying chamber efficiency as per

Mohapatra *et.al* (2013)

$$\eta_o = \eta_h \times \eta_c \text{ ....16}$$

d) Effect of Exhaust fan on drying Performance

In order to investigate the effect of incorporating an exhaust fan on drying performance, the drying system was tested with and without the fan at the exhaust section. Final moisture contents of the dried paddy were analyzed using a one (single factor) way analysis of variance (ANOVA) table. The factor considered was moisture content as per Hashemi (2009). This was done when drying with an Exhaust Fan (WF) and Without an Exhaust Fan (WOF).

3.7. Emissions performance

The assessment of the flue gas emissions used for drying was achieved by use of a Flue gas Analyzer model TESTO 350-MXL, made in Germany as shown in. Fig 3.10 as per Ivan *et al* (2013). The analyzer is capable of measuring, flue gas temperature, CO2 carbon dioxide content (%), O_2, CO (Carbon oxide ppm), SO_X Sulphur. The flue gas analyzer measured emissions from the rice husk combustor used for paddy rice drying as shown in Fig 3.10.

Figure 3.8: Rice husks Combustor

Figure 3.9: Paddy Drying Bed without an Exhaust Fan

Figure 3.10: Photo of Flue Gas Analyzer

3.8 Economic analysis

The economic analysis was performed by estimating and totaling up the equivalent money value of the benefits and costs of the dryer equipment to establish its viability (Swain *et al.*, ,2014). The cost benefit analysis was done for the rice husk fueled paddy dryer by considering the fixed and the variable costs used in the paddy rice drying and comparing the costs with that of having it dried in the sun. From analysis the viability of the drying equipment was determined.

Cost benefit ratio = Gross revenue/Total Drying costs

- Payback period is the time taken to recoup the capital investment and was calculated using the formula below;

  Payback period = Capital investment/Net income.

Table 3.4 Assumptions made in Economic Analysis.

Item	Assumption
Drying season, Months per year	Six Months
Number of batches per day using drier	3
Tones Dried per batch	0.22 tons
Investment cost of Drier	Kshs 150,000
Salvage Value of Drier	Assumption Kshs 20,000
Interest rate	15%
Economic Life of Drier	10 years
Number of days to dry in open sun	3 days

3.8.1 Drying costs

The total drying cost was calculated by adding up capital cost, fixed costs and the variable costs which covers energy and labor cost. The fixed costs include depreciation, interest on investment, insurance (0.5%) and maintenance costs as per Swain *et al.* (2014).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter presents and discusses results focusing on field survey and paddy drying system thermal performance results

4.1 Field Survey Results

The field survey results based on collected data from the paddy rice farmers and paddy rice millers in the Mwea Tabere scheme in Embu County with geographical coordinates of 0^o 45’ 55” S and of 37^o 21’ 14” E Kenya.

4.1.1 Demographic data

About 300 farmers were interviewed including 100 females and 200 males with age bracket 35 - 60 years. Their education level ranged from tertiary level constituting 60% while 40% had acquired primary education.

The farm sizes were 1 - 3 acres with production capacities ranging from one ton to two tons per acre. The other crops grown by farmers included tomatoes, beans and maize through irrigation by using water from the irrigation canal. The other information gotten from farmers was on drying of harvested paddy.

4.1.2 Moisture Content

The moisture content for the paddy at the farm level is presented during harvesting and after open sun drying. The results for paddy rice moisture content measurements are presented on Table 4.1.

Table 4.1 Paddy rice received by millers

Condition of Paddy Rice	Moisture Content % (wwb)
Harvested	25±0.2
Paddy after drying(harvested)	19±0.2

From Table 4.1 the average moisture content for the harvested paddy was at 25% ±0.2 (wb) as compared to 12-14% (wb) for safe storage. The moisture content after the farmers dry the paddy in the fields and on the road was 19% ±0.2 (wb). Most farmers sold paddy to the millers and to traders who dry and then sale to the millers. The results for the moisture content for the harvested paddy compares well with other similar studies done which reported moisture content of 24-30% ±0.2 (wb). (Purwadaria, 1995).

4.1.3 Need for Paddy Rice Drying Technology

From the field surveys it showed that about 98% of the farmers saw the necessity for developing a paddy rice dryer. Also 95.9% of farmers had problems with drying paddy rice due to wet and cloudy conditions during harvesting period.

4.1.4 Paddy Drying Technology and Milling

From the survey it was observed that paddy drying was a serious problem. About 100% of the farmers and millers dried the paddy out in the ground, on mats along the roads and open fields. Labor costs are increased due to handling including challenges of intermittent rains. Also 78% of the paddy rice received by millers was not adequately dried for milling as shown in Fig 4.1. Millers bought paddy rice from small scale farmers and traders with moisture contents of 20%±0.2 (wb) and 16%±0.2 (wb) respectively as shown in Table 4.2

Therefore, the millers dried the paddy further to moisture contents of 13%- 14% (wb) which is considered safe for storage and milling.

Table 4.2 Average moisture content for paddy delivered by farmers and traders.

Supplier	Moisture Content% (wb)
Farmers	20±0.2
Traders	16 ±0.2

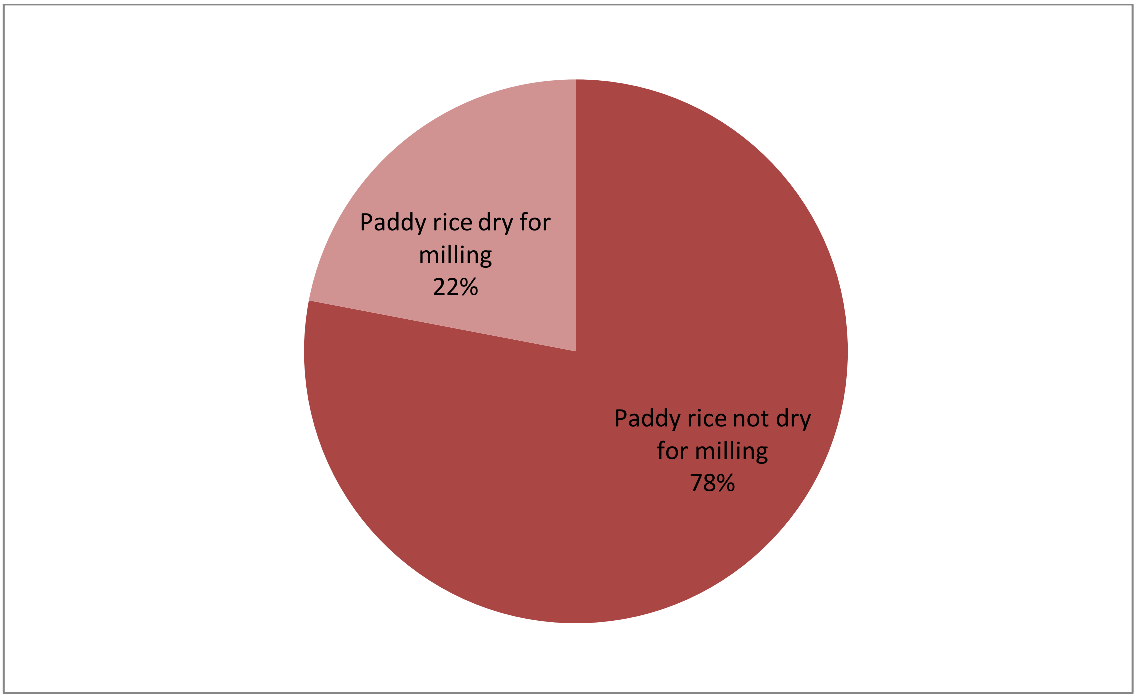


Figure 4.1: Results Paddy rice ready for Milling

4.1.5 Rice Husks Disposal

From the field survey, it was noted that 100% of the millers had challenges in disposing generated rice husks. Most millers dispose the waste husk generated by dumping it by the roadside and burning it. Others have bought land with open fields where they dump and after some time come to burn it.

4.2 Thermo physical Properties of Rice Husks

From Table 4.3 the average calorific value for waste husks sampled for three samples averaged, 13,200 kJ/kg and moisture content (wb) was 6.83%±0.1. According to Nasir and Umar (2015) the calorific value and moisture content of the husks from studies obtained was 14,000 kJ/kg and 6.0%, respectively. This compares well with values obtained from present results. The values of the ash content and the bulk density were 120 kg/m^3 while the ash content was 23.38%. The values reported by Jenkins *et al* .1999 was 122 kg/m^3 and 20.26% this compares well the results obtained. The analysis of thermo-physical properties of the rice husks were as shown in Table 4.3.

Table 4.3:Thermo physical properties of rice husks results

Parameters	Average
Bulk Density(kg/m^3)	120±0.3
Particle Density(kg/cu-m)	600±0.2
Calorific value kJ/kg(HHV)	13.200±0.4
Moisture (wwb) (%)	6.83±0.1
Volatile matter (%)	70.2±0.3
Fixed carbon (%)	15±0.3
Ash content (%)	23.38±0.3

4.3 Potential of Thermal energy from Rice Husks

With each of the 20 small millers at Mwea generating about 2-3 tons of husks per day the equivalent energy from this is about 12.4 to 18.6 TOE. With the country's paddy production of 90,000 to 96,000 tons, the husks generated per year is about18,000 to19,200 metric tons or 20% of the paddy produced. With an average calorific value of 13 MJ/kg the available renewable energy from paddy husk waste in the country is 5573-5944 TOE per year.

4.4 Paddy Rice Dryer Design Parameters

The results of the computed design parameters are summarized as on Table 4.4.

Table 4.4 Paddy Rice Dryer Design Parameters

Parameter	Units	Value	Remarks
Initial humidity ratio (ωi),	kgwv/kgda	0.16	From psychometric chart
Initial Enthalpy hf	kJ/kgda	68.0	From psychometric chart
Final Enthalpy hf	kJ/kgda	86	From psychometric chart
Final humidity ratio(ωf),	kgwv/kgda	0.0236	From psychometric chart
Mass of moisture evaporated	kg	47.3	Refer equation 4
Drying bed area	m^2	4	Refer equation 9
Volumetric air flow rate	m^3/s	0.45	Refer equation 5
Fan rating	kW	1	Refer equation 8
Total Useful Energy E	kJ/s	8.1	Refer equation 11

4.5 Paddy Drying Performance

The results for paddy drying performance utilizing the paddy husk powered system are presented in Table 4.5. Data collected was statistically analyzed using excel and SPSS programs. From the results it shows that paddy was 220kg of paddy was dried from a moisture content of 25.8% to 13.4% within 4hrs.

Similar experiments done showed that in order to dry paddy to get moisture contents of between 12 to 15 % (wb) has been realized in 4 hours. The results obtained are comparable with those by De Padua (2007) in which he obtained a moisture content of 14.5 after drying paddy for 4 hours.

4.5.1 Dryer Efficiency

The dryer efficiency was calculated taking maximum amount of dried paddy rice of 220 kg as shown in Table 4.5. The System efficiency for the dryer was computed by using equation 10 and thermal efficiency of the combustor computed using equation 11. The results for the computed efficiencies are presented on Table 4.6.

From Table 4.6 the overall system efficiency was found to be 25.5%, which compares well very well with overall efficiency of 24% reported by Mohapatra*et.al* (2013). While the thermal efficiency for the combustor was found to be 73%, studies from similar dryers by Dhanushkodi, *et .al.* (2015*)* achieved thermal efficiencies of 74%. The drying chamber efficiency was found to be 34.5%. These values are within the range of the others reported by. (Dhanushkodi, *et al.*, (2015) of 35% for a biomass cashew-nut husk powered dryer

Table 4.5 Paddy Drying Trials

Trial	**Paddy Layer**	**Paddy kg**	**Initial MC% (wb)**	**Final MC% (wb)**	**Inlet Temp ^{o}C**	**Exhaust Temp ^{o}C**	**Husks Consumed {kg/hr}**	**Drying Duration Hrs**
1	Top	220	25.8	13.5	44.2	32.5	2.8	4
	Bottom	220	25.8	13.0	44.2	32.5	2.8	4
2	Top	220	25.6	13.2	45.1	33.6	2.6	4
	Bottom	220	25.6	12.8	45.1	33.6	2.6	4
3	Top	220	26.0	14.2	45.7	33.8	2.7	4
	Bottom	220	26.0	13.7	45.7	33.8	2.7	4
Average	**220±0.2**	**25.8±0.1**	**13.4±01**	**45±0.1**	**33.3±0.1**	**2.7±0.1**	**4±0.1**	**Average**

Table 4.6 Paddy Rice Dryer Efficiencies

Section	1st trial Efficiency%	2nd Trial Efficiency%	3rd Trial Efficiency%	Average Efficiency%
Overall system efficiency	26.2±0.2	25±0.2	25.3±0.2	25.5±0.2
Drying chamber efficiency	35.6	34.2±0.2	33.7±0.2	34.5±0.2
Combustor Thermal Efficiency	73.8±0.2	73.1±0.2	72.1±0.2	73±0.2

4.5.2 Drying performance

The results on moisture content percent reduction for various treatments over a period of 240 minutes is shown on Table 4.7. Treatments for various loadings and T1, T3 and T5 is for drying with Exhaust Fan and Treatments T2, T4 and T6 is drying without exhaust fan. The loading of the paddy was varied using different loading that is for T1 and T2 =100kg, T3 and T4= 150kg ,T5 and T6=220.The initial moisture content for all the trials that is T1,T2,T3,T4,T5 and T6 was maintained at 26%.The inlet drying temperature was maintained at between 42^{o}c to 4^{o}c and the airflow was maintained at 0.45m^3/s.

Table 4.7 Moisture removal of treatments

Sample	Average moisture removal after 240 min (%)					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
1	52.8	50.2	49.4	39.1	49.4	42.2
2	50.7	51.2	50.6	40.1	49.6	42.5
3	52.1	50.1	51.4	42.6	50.6	42.2
AVG	51.9	50.5	50.5	40.6	49.9	42.3
STDEV	1.1	0.6	1.0	1.8	0.6	0.2

Table 4.7 above shows that after 240 min, of drying that at higher loading of the paddy at 220kg that is for trial T5 and T6. Trial T5 is the most efficient drying since 49.9% of the moisture is removed compared with T6 at 42.3%. Also for T3 and T4 in which the drier was loaded with 150kg similar performance is seen that for T3 the moisture removal is more where an exhaust fan was used. But at Lower loading that is at TI moisture removal is 51.9% and T2 is 50.5% hence there is no much difference in moisture removal with or without using an exhaust at lower loading of paddy to drier at 100kg

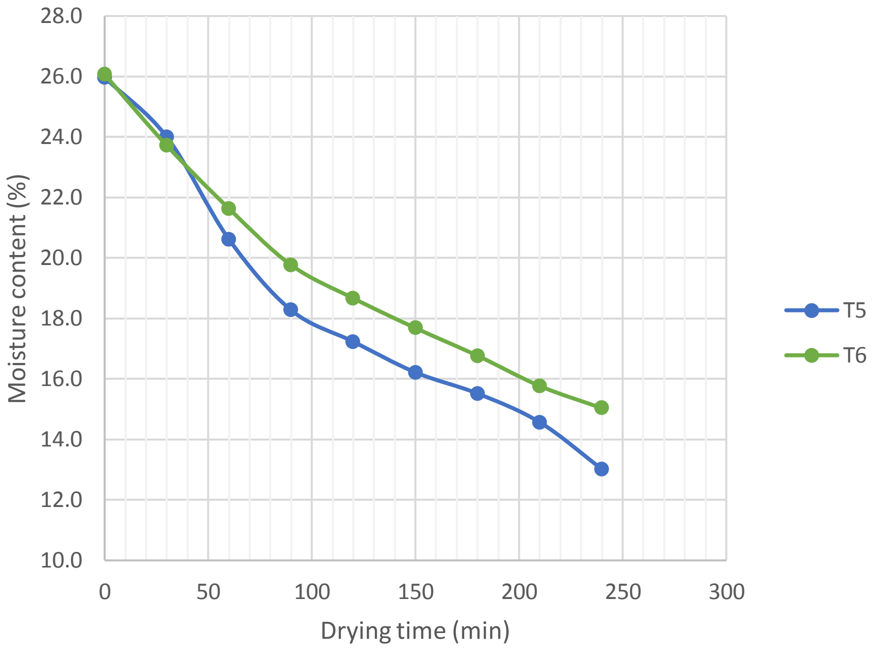


Figure 4.2: Average rate of paddy drying

Figure 4.3 above show that treatments T5 and 6 (T5 where the exhaust fan used to extract moisture from the drying chamber and T6 exhaust fan not used) in which 220 kg of paddy at initial moisture content of 26% and 0.3m depth was dried to 13% moisture.It was observed that drying 220kg of paddy using the exhaust fan(T5) makes the drying faster compared to drying without exhaust fan(T6). Similar studies done by (Heshami *et al.*, 2009) showed that incorporating an exhaust fan in drying enhances the process by achieving the desired moisture content than the dying without a fan.

4.5.3 Effect of Exhaust Fan on Moisture Removal

Table 4.8 shows Analysis of Variance for various treatments on moisture removal

Table 4:8 ANOVA Single factor for all treatments

Groups	Count	Sum	Average	Variance
T1	3	155.6058	51.86861	1.199572
T2	3	151.5082	50.50273	0.408539
T3	3	151.3955	50.46518	1.001549
T4	3	121.8217	40.60724	3.233592
T5	3	149.583	49.861	0.390533
T6	3	126.8441	42.28136	0.03128

ANOVA						
Source of	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between	351.46476	5	70.29295	67.31897	2.33E-	3.105875
Within Groups	12.53013	12	1.044177			
Total	**363.99489**	**17**				

From computations in Table 4.8 the null hypothesis is rejected since p-value is less than 0.05 and F-calculated is greater than F- critical. Therefore, the variations in moisture removal are significant. Loading of paddy with an exhaust fan gives significantly faster in moisture removal. This results concur with studies done by Heshami *et al.*,2009. Hence this shows use of exhaust fan increases drying rate.

Table 4.9 ANOVA Single factor for treatments with exhaust hood and fan

Groups	Count	Sum	Average	Variance
T1	3	155.6058	51.86861	1.199572
T3	3	151.3955	50.46518	1.001549
T5	3	149.583	49.861	0.390533

ANOVA						
Source of	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between	6.3651516	2	3.182576	3.684029	0.090417	5.143253
Within	5.1833072	6	0.863885			
Total	**11.548459**	**8**				

Table 4.9shows that with moisture exhaust hood and fan (T1, T3 and T5), variation of amount of paddy per batch loaded did not significantly affect drying efficiency

Table 4.10 ANOVA Single factor for treatments without exhaust hood and fan

Groups	Count	Sum	Average	Variance
T2	3	151.5082	50.50273	0.408539
T4	3	121.8217	40.60724	3.233592
T6	3	126.8441	42.28136	0.03128

ANOVA

Source of	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	168.31425	2	84.15712	68.72941	7.32E-05	5.143253
Within Groups	7.3468226	6	1.22447			
Total	**175.66107**	**8**				

Table 4.10 above shows that without a moisture exhaust hood and fan (T2, T4 and T6), the quantity of paddy loaded per batch to dry significantly affects the drying efficiency.

4.6 Emissions from Combustion Chamber

The emissions measurements for the flue gases from the combustor were done using a flue gas analyzer.

Table 4.11 shows the results for the emissions of the flue gases used in drying the paddy

Table 4.11 Average Emissions Results

Test	CO_2	CO (ppm)	SOX (ppm)	NOX (ppm)
1	8.8%	64.8	35.3	102.7
2	10.9%	59.5	36.3	100.7
3	9.2%	60.5	36.8	102.7
Average	9.6%	61.6	36.2	102.0
NEMA LIMIT	Not Defined for this Equipment			
OSHA Limit	5000	50-200	35.3-36.3	100.7-102.7

From Table 4.11 the CO_2 concentration was between 8.8% to 10.9% CO (ppm) emissions range from 59.5 to 64.8 ppm, the SO_X range from 35.3 to 36.3 ppm and

NO_X range 100.7 to 102.7ppm. These results compare well with similar studies on combustion of rice husks. Thipwimon *et.al. (*2009) conducted a study on emissions for combustion of rice husks to produce power. The results showed that CO_2 concentrations were about 10%(ppm). Studies done by Ivan *et.al* (2013) on production of gas emissions from rice husk biomass as a heat source ranged between 30.7 to 79.7 ppm for CO emissions. Aneta *et al* (2011) studied the modelling of pollutants concentrations from rice biomass combustion process husk and found that SOX emissions ranged between 150 ppm to 155 ppm. On the basis of these findings, the rice husks burnt in the furnace were within the acceptable exposure limits as set out by the Occupational Safety and Health Agency (OSHA) (Tsietsi *et al.,* 2013). Hence the developed system is safe for use in drying paddy rice in Kenya and other countries.

4.7 Economic Analysis

The economic analysis was done by computing the fixed costs, variable costs and the benefits and the results are presented on Table 4.12 and 4.13.

i) Fixed costs

The fixed costs to calculate are Depreciation, Interest on Investment, Maintenance Costs and insurance costs. In calculating depreciation of the paddy drier the straight line depreciation method was used as per Swain., 2014 in this the purchase price or fabrication costs of the drier is considered and the salvage value over its economic life that was taken be Ten years.

$$Depreciation = \frac{\frac{Purchase\ price}{Cost\ of\ drier} - salvage\ value}{Useful\ economic\ life}$$

Drier Cost Kshs - 80,000

Salvage Value=-20,000

Useful economic Life=10years

$$Depreciation = \frac{80,000 - 20,000}{10}$$

=Kshs 6,000

The interest on investment was computed considering the purchase price and the salvage value.

$$Average\ value = \frac{Purchase\ Price\ + Salvage\ Value}{2}$$

$$Average\ value = \frac{80,000 + 20,000}{2}$$

Average Value=Ksh 30,000

Interest=30,000*15%=4500

The annual maintenance costs taken to be 15% of the drier cost

Maintenance cost=15% 80,000=Kshs 12,000.

Insurance was considered to be 0.5% of the drier cost=0.5 * 80,000=400

Total Fixed costs=6,000+4500+12,000+400=22,500

Table 4.12 Summary of the Fixed costs

S/N	ITEM	COST(Kshs)
1	Depreciation	6,000
2	Interest on investment	4,500
3	Maintenance costs	12,000
4	Insurance	400
	Total Fixed Cost	**22,900**

ii) Variable Costs

The variable costs cover labor, electrical energy and fuel costs

Labour cost computations was based on having two operators of the drier paid at Kshs 500 per day. Working for 25 days in a month for six months

Labour 500*2*25*6=150,000

Electrical energy computations obtained from the power rating of motor at 0.75 kw, working for 12 hours in a day for 25 days for six months.

(0.75*12*25*60) * Kshs17 = Kshs22,950/=

Though fuel is considered to be free taken as waste, the cost of collecting a bag was used.

To dry one batch, it consumes about 3 to 4 kg hence for three batches need about 12 kg which is one sack.

To collect one sack, it costs Kshs 50

Fuel cost=50*25*6=7500

Total Variable Costs = Kshs [150,000+22,950+7,500] = Kshs 180,450

Total Drying Cost = Kshs [80,000+22,900+180,450] = Kshs [283,350.]

Table 4.13 Summary of the yearly Variable costs

S/N	ITEM	COST(Kshs)
1	Electrical energy	22,950
2	Fuel costs	7500
3	Labor costs	150,000
	Total Variable Cost	**180,450**

iii) Benefits

The benefits were computed by considering the income generated through drying of the paddy. The benefits were calculated by considering what the farmers are willing to pay for a dried sack of Paddy weighing between 65 to 70 Kg. This was from the fact that before drying when farmers sell paddy to middlemen for drying and sell to millers the price was less by Kshs 200 to 300 per bag of 70 kg.

Also from the field survey it was found out that to dry a bag of paddy costs between Kshs 150 to 250. Hence the price to use in charging the farmers or millers per bag of paddy is Kshs 200. In a day the dryer can do thee batches of 250 kg each hence drying 750 kg or 11 bags of 65 to 70 kg.

The drying was done for 25 days in a month for only six months in a year.

Gross Revenue/Income = (200*11*25 days) *6 months = Kshs330,000

Cost Benefit ratio=Gross revenue/Total Costs = 330,000/283,350 = 1.16

Pay Back period = Capital Investment/Net Income = 80,000/ (330,000-283,350) =1.71

The results for cost benefit ratio of 1.16 and the payback period of 1.71 years compares well with values obtained from other researchers. Bhandari and Gaese (2008) who carried out an economic evaluation of paddy dryers of various sizes utilizing rice husks as fuel and he found out that Cost Benefit ratio ranged from 1.23 to 2.24 and the payback period was between 1.4 to 5.35 years. Also Swain *et al. (*2014) from his study on the performance evaluation of cashew nut Biomass driers he found out that its cost benefits ratio was 1.4 and the payback period of 1.5 years. From this economic analysis it shows that the dryer is suitable for use in Mwea Irrigation scheme and other rice growing regions.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

a) Post-harvest losses amounting to 30-40% of total output of paddy rice is major problem in in rice growing of Kenya especially during rainy and cloudy conditions since most farmers rely on sun drying method. Some developing countries have adopted flatbed dryers whose challenges are mainly non-uniform drying of grains. Therefore, in this study we successfully developed a flat-bed rice biomass powered drying system for paddy in Mwea Tabera scheme, in Embu County Kenya.

b) Afield survey was conducted in Mwea Rice Irrigation scheme and the results of the survey were used in designing and constructing a biomass rice husk fueled paddy drying system with 250kg drying capacity per batch.

c) From the field survey it was found out that 100% of the farmers and millers sun dried their paddy on out in the open ground. Also 98% of the farmers saw the need of developing drying system for paddy rice. . On the other hand, 78% of the millers surveyed received partially dried paddy rice for milling.

d) From the results on performance of the 220 kg paddy drying system shows that the system is capable of drying paddy from 24-26% (wb) to 14%(wb) within 4 hours. The average thermal efficiency of biomass combustor was computed to be 64%±0.2 which compared well with similar combustors widely used in paddy drying.

e) It was noted that the incorporation of an exhaust fan in paddy dryer improved the dryer performance by drying faster with one hour.

f) The paddy drying system demonstrated the cost benefit ratio of 1.16 and the payback period of 1.71 years and compared with other researchers on paddy drying.

g) On the basis of these findings, we recommend paddy farmers in Kenya should adopt this technology in order to attain a reduction in post-harvest losses.

5.2 Recommendations

i) It is recommended that the fabricated dryer should be adopted in rice growing areas of Kenya.

ii) Improvements for the dryer performance can be achieved by further modification which include, Re-circulation of pre-heated air exiting dryer chamber to the flat bed inlet.

iii) Further studies should be done to analyze the use of the flue gases from the combustor to dry other crops like maize other and other horticultural crops.

REFERENCES

Akal,D., Kahveci,K. and Cihan, A; 2007. Mathematical Modeling of Drying of Rough Rice in Stacks. *Food Science and Technology International Journal*, 13 (6): 437-445.

Aneta M., Małgorzata, W and Monika Z. 2011. Modelling of Pollutants concentration from the Biomass Combustion Process. *Chemical and Process Engineering,* 32 (4): 423-433.

Axtell, B. (2002). *Drying Food for Profit: A guide for Small Business,* UK:Intermediate Technology Development Group Publishing Ltd. London.

Bala. B. K (1997). Drying and Storage of Cereal Grains, Taylor and Francis Publishers Inc. Enfield, New Hampshire 03748, USA.

Bhandari, R. and Gaese. H. 2008.Evaluation of Box Type Paddy Dryers in South Sumatra,Indonesia.. *Agricultural Engineering International: the CIGR Ejournal. Manuscript* FP 08011.

Bakker. F, Montross M.,. Liu, Q and Maier,D., 1995 *Analysis of Continuous flow Grain Dryers,* Department of Agricultural Engineering Michigan State University. East Lansing USA.

Brook, R. C. and Foster ,G. H., 1981. *Drying, Cleaning and Conditioning, In Handbook of Transportation and Marketing in Agriculture, Volume II: Field Crops, CRC* Press. Boca Raton.

Chayan K.S. . Ahraful. A, Alam.M, and Prasanta K. “Field Performance of BAU-STR Paddy Dryer in Bangladesh” *Presented at the 2017 Annual International Conference for ASABE* ,Bangladesh

De Padua D. B. “Status of rice postharvest industry in the Philippines”. *Presented at ARF annual rice forum 2007 and NAST roundtable discussion on PA 2020, November 2007*, Traders Hotel, Manila.

Dhanuskodi. S, Vincent. H.W,and Shudakar. K.,2015. Design and Performance Evaluation of Biomass Dryer for Cashewnut Processing, *Advances in Applied Science*, 6(8):101-111.

Dhanushkodi. S, Wilson V H and Sudhakar, 2015. Life cycle cost of solar biomass hybrid dryer systems for cashew drying of nuts in India. *Environmental and Climate Technologies*, 15(6): 22–33.

Ezekoye, B.A., and Enebe, O.M. (2006).Development and Performance Evaluation of Modified Integrated Passive Solar Grain Dryer.The Pacific Journal of Science and Technology, 7 (2): 185- 190.

FAO.,1998. Drying of high moisture paddy rice. *Post-Harvest E-mail Conference Draft Summary.1(2*): FAO, Rome, Italy.

Fellows, P. 1997. *Guidelines for Small-Scale Fruit and Vegetable Processors*, FAO Agricultural Services Bulletin 127. Rome.

Gummert, M. 2007. *New rice husk furnace takes off in Vietnam In Rice Research for Intensified Production and Prosperity in Low Land Ecosystem*. IRRI Agricultural Engineering Unit. Philippines.

Fudholi A, Othman M Y, Ruslan M H, Yahya M, Zaharim A and Sopian K,2011. “Techno-economic analysis of solar drying system for seaweed in Malaysia” *In 2011 Proceedings of the 7th IASME/WSEAS Int. Conf. on Energy, Environment, Ecosystems and Sustainable Development (EEESD,11), Malaysia.*

Hashemi, J. and Shimizu, N., 2008. Investigation of fissure formation during the drying and post-drying of japonica aromatic rice. *Journal of Agriculture and Biology*.10(2):179-184.

Hashemi, J., Reza,T. and Kimura, T., 2009. Effects of Discharge Fan on the Drying Efficiency in Flat-bed type Dryer. *International Journal of Agricultural and Bio Systems Engineering*,3(1):45-49.

Ichsani, D. and Dyah, W. A. 2002. "Design and Experimental Testing of a Solar Dryer Combined with Kerosene Stoves to Dry Fish," *American Society of Agricultural and Biological Engineers*, July 28-31, 2002, pp. 1-3. DOI: 10.13031/2013.10854

Ivan V., Bozen V. and Julius P., 2013. Production of gas emissions from biomass heat, *Engineering Mechanics,* 20(4):289-297.

Jenkins B. M., Baxter. L.L., Miles. T.R. Jr., and Miles.T.R.,1999. Combustion properties of biomass. *Journal of Fuel Processing Technology*. 54:17-46

Karekazi, S. and Kithyoma, W., 2005. *Sustainable Energy in Africa, Cogeneration and Geothermal in East Africa and Horn of Africa-Status and Prospects*, AFREPREN/FWD. Nairobi.

Karekezi, S. and Kithyoma, W., 2006. *Bioenergy and Agriculture: Promises and Challenges* AFREPREN/FWD. Nairobi.

Kaaya, A.N. and Kyamuhangire, W., 2010. Drying maize using biomass-heated natural convection dryer improves grain quality during storage. *Journal of Applied Science*. 10(11): 967-974.

Lantin, R., (2006). Post-harvest Operations. International Rice Research Institute, Philippines (IRRI) , cited by http://www.fao.org/inpho/, Accessed on 10 th Sept 2018.

Maier, D. and Fred, W. "Grain Drying Systems Facility Design" Presented in 2002 at the *Conference of Grain Elevator and Processing Society,* st Charles, Illinois USA.

Mendoza, E. and Quitco, R., 1984. *Quality deterioration and value loss in grain in 'coming to grips with the wet season grain handling problems in Southeast Asia*.ASEAN Crops Post-Harvest Programme. Manila.

Mohapatra, S., Lakshmi, V., and Mahanta, P., 2013. Performance Evaluation of Natural Convection Grain Dryer using Phase Change Material for Quality Drying of Paddy. *International Journal of Agriculture and Food Science Technology*. 4(6):523-530.

Ministry of Agriculture. 2009. *National rice development strategic plan (2008-2018)*. GOK Printer. Nairobi.

Nasir, A. G, Umar. Z. 2015. Rice straw & husk as potential sources for mini-grid rural electricity in Nigeria. *Journal of Applied Sciences and Engineering Research*. 4(4):526

Nathan,A.B. Thoruwa, T., Moturi, M.C.Z. and Makanga J.T.2015.Assessing the Effect of an Exhaust Fan on the Performance of a Rice Husk Fuelled, Flat Bed Paddy Dryer , The International Journal of Science and Technoledge. 8 (102-106).

Proctor, D.. 1994. *Grain Storage Techniques; Evolution and Trends in Developing Countries*. FAO Agricultural Services. Rome, Italy.

Phan, H. (2009). *Agricultural Engineering and Agro-products Processing towards Mechanization and Modernization in Rural Areas"at Nong-Lam University*,11-12 December. Ho ChiMinh City.

Phan. H., Quang, V., Tran ,T., Thanh, T., Tran, V. and Nguyen, T., 2010. *Flat-bed dryer Sub-Component Reports to CARD Project*.,Nong-Lam University,Vietnam.

Purwadaria, H. K.,"Problems and Priorities of Grain Drying in Indonesia "Presented at 1995 International Conference for Grain Drying Proceedings held at the FAO Regional Office Asia. Bangkok, Thailand,.

Sahay, K.M. and Singh, K. K. (2001), Unit Operations of agricultural Processing, Central Institute of Agricultural Engineering, Vikas Publishing House PVT Ltd, Bhopal.

Somchart, S. Swasdisevi, T, Somboon,W. Adisak S and Boonrueng S. (2000). Cyclonic Rice Husk Furnace and Its Application on Paddy drying,*Internatlonal Energy Joumal*.1(2):67-75.

Singh, R; Maherhweri, R.C.; and Ojha, T.P. 1980 Development of husk rice husk fired furnace. *The British Society for Research in Agricultural Engineering* , pp.109-120.

Swain S, Din M, Chandrika R, Sahoo GP, Roy SD .2014. Performance Evaluation of Biomass Fired Dryer for Copra Drying: A Comparison with Traditional Drying in Subtropical Climate. *J Food Process Technology,* 5(1): 294-301.

Teter N (1987). Paddy Drying Manual. Agricultural Services Bulletin No. 70, FAO, Rome. 123 pp

Tsietsi J P., Huberts, R. and Muzenda E. 2013. Emissions analysis from combustion of eco-fuel briquettes for domestic applications. *Journal of Energy in Southern Africa*. 24(4): 30-36

Tonui, K,Mutai, K. Mutuli, D.. Mbuge, O and Too, K. 2014. Design and Evaluation of Solar Grain Dryer with a Back- up Heater. *Research Journal of Applied Sciences, Engineering and Technology* .7 (15): 3036-3043.

Thipwimon, C. Shabbir, H .and Suthum,P. 2009. Emission Assessment of Rice Husk Combustion for Power Production,. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 3(5):625-630.

Waswa, S., Syagga, M. Dulo,S. O.and Kamau, G. N., 2002. Rice Husk Ash Cement– An alternative pozzolana cement for Kenyan building Industry. *Journal of Civil Engineering*, 8: 13 – 26.

Wehrspann, J. May 1998, Sizing up grain dryers, http://farmindustrynews.com/,cited Nov 2015

Werther, J . Saenger, M and Siag, Z., 2000. Combustion of agricultural residues. *Progress in Energy and Combustion Science*, 26(1): 1–27.

Wimberley, J. E. 1983. *Technical Handbook for the Paddy Rice Post-Harvest Industry in Developing Countries.* International Rice Research Institute. Manila..

World Bank. 2011.*World Bank Report on the Missing Food.* "*The Case of Postharvest Grain Losses in Sub-Saharan Africa "Report No. 60371-AFR*, World Bank1818 H Street, Washington, DC 20433.

APPENDICES

Appendix I: Farmers Questionnaires

Instruction

This questionnaire is designed to assist in collecting information with regard to processing of rice. Any information gathered will be used for the purposes of research only

Name of Enumerator:
…………………………………………………………………………….

1 a)Name of respondent………………………………………Contact………………………..

b) Nearest town:
……………………………………………………………………………….…

b) Sex - Male/Female

c) Location………………………… Sub location……………………….. Village………….

d) Level of Education…………………………………………..

2. a)is your farm under the National Irrigation Board(NIB)-Yes/No.

3. What is the average size of your field? (a)Less than 2 acres (b) 2acres

(c) 3acres (d) over 4 acres (e)Over 4 acres

3. Which month(s) of the year do you plant? (a) March (b) May

(b) June (c) July (d) other………..

4. Which month(s) do you harvest? (a)May (b) June (c) July (d) September

(d) October (e) November (e) December

5. How long does it take from planting to harvest?

(a) 3months (90 days) (b) 4 months (120 days) (c) 5 months(150 days) (d) Over 150 days

6. How many times do you harvest in a year? (a) 1 harvest (b) 2 harvests (c) 3 harvests

7. What quantity do you produce per acre? (a) 2 bags (b) 3bags (c) 4bags

(d) 5 bags (e) 6 bags (f) over 7 bags

8. What are the main obstacles to production that you face now?

(a) To increase number of acres (b) money to increase output

(c) Land to do the farming (d) labor requirements (e) Drying the produce

9. a)at harvest is the rice dry enough for threshing? YES/NO

d) If NO how do you dry? i) Dry in the field on racks ii) Stacking it to dry iii) Drying it on the ground in the field

10. After threshing do you dry the rice further before selling to the millers or traders? YES/NO

11. Do you use a dryer for drying after threshing? (a) Yes (b) No

11a.If no, how then do you dry your paddy rice? (a) Sun drying (b) Shade drying.

11b.For the method you use how long does it take to dry (i) half a day (ii) One day (ii) Two days (iii) Three days

11c.How man man-days do you use for drying

12. Do you need a dryer? (a) Yes (b) No

13. From the quantity you produce, do you think you need a dryer? (a) Yes (b) No

14. Can you alone afford a dryer of about Kshs300,000 (a) Yes (b) No

15. if not, are you prepared to pool resources with others and buy one? (a) Yes (b) No

16. Are you also prepared to form co-operative farmers together for increased productivity?

(a) Yes (b) No

17. Do you cultivate rice every year? (a) Yes (b) No

18. How would a dryer enhance your production capacity?

(a) Quality of rice grain (b) to increase quantity (c) reduce losses

19. How many crops can you produce in a year? (a) 1 crops (b) 2 crops (c) 3 crops

20. What mode of heating will you prefer? (a) LP G (b) Electricity

(c) Diesel (d) vegetable waste (rice husks) e) solar heating

21. Will you have convenient space for the installation of the dryer? (a) Yes (b) No

THANK YOU FOR YOUR TIME

Appendix II: Millers

Name of Enumerator…………………………………………………………………..

1. a) Name and address of milling company…………………………………………………

1. b) Name of respondent………………………………………

c) Sex - Male/Female

2. Where do buy the paddy from? (I)NIB farmers (ii) Private farms (iii) both

3. What is the milling capacity? (i) 5 bags /hr. (ii) 5 -7bgs/hr. (iii) Over 7bgs/hr. (iv) Others specify………………………………………..

4. a) when you buy the rice is it dry for milling? YES/NO

4.b) If no how do you dry the paddy (i) In the open sun on roads (ii) Using a solar drier(iii) Artificial dryer

4.c) How many man days do you use to dry a tone of paddy (i) 2 man-days (ii) 3 man-days iii) 4 man-days

4. d) for artificial dryers how much fuel do you use to dry a tone of paddy a) five liters ii) six litersIV) seven liters v) eight liters

5. Do you consider drying as a serious problem in rice production? YES/NO

6. From the quantity you produce, do you think you need a dryer? (a) Yes (b) No

7. Can you afford a dryer of about Kshs 700,000 (a) Yes (b) No

8. if not, are you prepared to pool resources with others and buy one? (a) Yes (b) No

9. Do you have a challenge in waste disposal of the rice husks? YES/NO

10. How do you dispose the waste generated from the mill i) Burning in the field ii) Dumping in the road sides

11. What mode of heating will you prefer? (a) LP Gas (b) Electricity

C) Diesel d) Kerosene (d) rice husks) e) solar heating

THANK YOU FOR YOUR TIME

Appendix III: Results for Dryer Testing

12) Date: 18/11/15

Weight of Paddy 220kg

Rice husk used=3kg per hour

Results for Drying at 0.3m depth-With an Exhaust Fan

Time	**Start 9.30 am**	**10.am**	**10.30 am**	**11.00 am**	**11.30 am**	**12.00 Noon**	**12.30 pm**	**1.00 pm**	**1.30 pm**
Moisture Content-Top%	25.8	24.0	21.0	19.0	18.2	17.0	16.0	15.5	13.5
Moisture bottom%	26.6	23.5	20.0	18.5	17.0	16.8	16.0	15.0	13.0
Inlet Temp ^{o}c	42.0	43.0	42.3	43.5	43	43.4	45.0	44	43.7
Exhaust Temp ^{o}c	31.6	31.8	32.7	32.6	32.0	33.5	34.0	32.0	32.5
Ambient Temp ^{o}c	20.0	21.0	21.5	22.0	22.5	23.0	23.2	23.3	24.0
Relative humidity	68.1	67.5	67.0	66.6	65.2	64.0	64.2	63.5	62.0

Ambient%									

xiii) Date: 19/11/15

Weight of Paddy 220kg

Rice husk used=3kg per hour

Results for Drying at 0.3m depth-With an Exhaust Fan

Time	**Start 9.30 am**	**10.am**	**10.30 am**	**11.00 am**	**11.30 am**	**12.00 Noon**	**12.30 pm**	**1.00 pm**	**1.30 pm**
Moisture Content-Top%	25.6	24.3	21	18.7	17.5	16	15.5	14.5	13.0
Moisture bottom%	25.6	23.5	20	17.4	16.8	15.8	15.2	14.0	12.8
Inlet Temp ^{o}c	41.0	42.5	43.0	45.0	46.2	44.0	44.5	44.0	43.7
Exhaust Temp ^{o}c	30.6	31.0	32.2	32.6	33.8	32.1	32.5	32.0	32.5
Ambient Temp ^{o}c	20.0	21.0	21.2	23.5	24.0	24.2	24.5	24.0	24
Relative humidity Ambient%	68.0	67.2	66.5	65.1	64.8	63.5	63.2	62.0	62.0

xiv) Date: 20/11/15

Weight of Paddy 220kg

Rice husk used=3kg per hour\

Results for Drying at 0.3m depth-With an Exhaust Fan

Time	Start 9.30 am	10.00 am	10.30 am	11.00 am	11.30 am	12.00 Noon	12.30 pm	1.00 pm	1.30 pm
Moisture Content-Top%	26.0	24.2	21.2	18..1	17.4	16.1	15.3	14.4	12.6
Moisture bottom%	26.2	24.5	20.5	17.2	16.5	15.6	15.1	14.0	12.4
Inlet Temp ^{o}c	40.1	43.2	43.4	44.6	45.7	46.0	45.1	45.6	44.6
Exhaust Temp ^{o}c	30.2	30.5	31.2	33.2	33.8	34.2	33.0	32.2	31.0
Ambient Temp ^{o}c	19.0	20.0	21.5	22.5	24.0	24.2	24.5	24.0	24.0
Relative humidity Ambient%	68.3	67.3	66.4	66.1	66.2	65.5	64.2	62.1	62.0

vi) Date: 21/11/15

Weight of Paddy 220kg

Rice husk used= 3kg per hour

Results for Drying at 0.3m depth-Without Exhaust Fan

Time	**Start 9.30 am**	**10.am**	**10.30 am**	**11.00 am**	**11.30 am**	**12.00**	**12.30 pm**	**1.00 pm**	**1.30 pm**
Moisture Content-Top%	25.9	25.2	24.0	23.2	22.5	21.3	20.2	18.6	18.1
Moisture bottom%	26.2	22.0	19.4	16.4	15.3	14.5	13.4	12.8	12.0
Inlet Temp ^{o}c	42.1	42.5	44.8	45.0	46.5	46.1	47.1	46.2	43.3
Exhaust Temp ^{o}c	31.0	30.1	32.3	33.1	33.5	33.6	34.0	33.5	32.5
Ambient Temp ^{o}c	19.5	20.2	21.6	22.2	23.0	23.5	24.5	24.0	24.0
Relative humidity Ambient%	69.1	68.0	67.2	66.5	67.1	66.0	64.5	63.4	62.0

vi) Date: 9/5/15

Weight of Paddy 220kg

Rice husk used= 3kg per hour

Results for Drying at 0.3m depth-Without Exhaust Fan

Time	**Start 9.30 am**	**10.am**	**10.30 am**	**11.00 am**	**11.30 am**	**12.00 Noon**	**12.30 pm**	**1.00 pm**	**1.30 pm**
Moisture Content-Top%	26.0	25.5	24.1	23.0	22.0	21.1	20.0	18.5	18.0
Moisture bottom%	26.2	22.1	19.0	16.5	15.0	14.0	13.5	13.0	12.0
Inlet Temp ^{o}c	43.0	44.0	46.2	44.3	46.1	43.0	47.0	46.0	43.0
Exhaust Temp ^{o}c	31.5	30.8	31.0	31.6	32.0	32.6	33.0	33.5	32.5
Ambient Temp ^{o}c	20.5	21.2	21.5	22.0	23.5	23.5	24.0	24	24
Relative humidity Ambient%	69.0	68,0	67.1	66.0	67.1	66.0	64.1	63.0	65.2

vi) Date: 9/5/15

Weight of Paddy 220kg

Rice husk used= 3kg per hour

Results for Drying at 0.3m depth-Without Exhaust Fan

Time	**Start 9.30 am**	**10.am**	**10.30 am**	**11.00 am**	**11.30 am**	**12.00 Noon**	**12.30 pm**	**1.00 pm**	**1.30 pm**
Moisture Content-Top%	26.0	25.5	24.1	23.0	22.2	21.1	20.0	18.5	18.2
Moisture bottom%	26.1	22.0	19.2	16.5	15.0	14.1	13.5	13.2	11.9

Inlet Temp ^{o}c	43.0	44.1	46.1	44.0	46.5	43.0	47.1	46.0	43.0
Exhaust Temp ^{o}c	31.0	31.8	33.4	31.6	33.6	31.2	33.8	33.5	31.5
Ambient Temp ^{o}c	21.2	22.5	22.5	23.0	23.2	23.5	24.0	24.0	24
Relative humidity Ambient%	69.5	68.3	66.9	66.1	66.1	66.0	64.3	63.1	62.4

Appendix IV: Moisture Content of Paddy by Drying Time

Treatment	Samples	Paddy layer	Drying time (min)									Moisture reduction after 240 min (%)
			0	30	60	90	120	150	180	210	240	
T1	1	Top	26.5	23.5	21.5	19.0	16.5	15.1	14.5	14.0	13.0	50.9
		Bottom	26.5	23.0	21.0	18.0	15.1	14.2	13.5	13.0	12.0	54.7
	2	Top	26.0	23.0	22.0	19.0	16.0	15.5	14.4	14.0	13.1	49.6
		Bottom	25.9	22.7	21.5	18.0	15.1	14.2	13.3	12.9	12.5	51.7
	3	Top	26.0	24.0	22.5	20.0	17.5	16.0	15.5	14.3	13.0	50.0
		Bottom	26.2	23.3	21.4	19.2	16.0	15.2	14.5	13.3	12.0	54.2
	AVG	Top	26.2	23.5	22.0	19.3	16.7	15.5	14.8	14.1	13.0	50.2
		Bottom	26.2	23.0	21.3	18.4	15.4	14.5	13.8	13.1	12.2	53.6
		Avg	26.2	23.3	21.7	18.9	16.0	15.0	14.3	13.6	12.6	51.9
T2	1	Top	26.0	23.2	22.5	18.0	16.7	15.1	14.5	14.0	13.5	48.1

		Bottom	26.2	23.0	20.5	17.5	16.0	15.5	14.0	13.0	12.5	52.3
	2	Top	26.1	23.0	19.5	17.0	16.1	15.0	14.5	14.0	13.3	49.0
		Bottom	26.2	23.1	22.5	18.5	16.1	15.5	14.1	13.0	12.2	53.4
	3	Top	25.7	24.6	22.2	19.4	16.5	15.0	14.7	14.1	13.3	48.2
		Bottom	26.0	24.0	21.5	18.5	16.0	15.5	14.0	13.0	12.5	51.9
	AVG	Top	25.9	23.6	21.4	18.1	16.4	15.0	14.6	14.0	13.4	48.5
		Bottom	26.1	23.4	21.5	18.2	16.0	15.5	14.0	13.0	12.4	52.6
		Avg	26.0	23.5	21.5	18.2	16.2	15.3	14.3	13.5	12.9	50.5
T3	1	Top	25.0	23.0	20.0	18.0	17.0	16.0	15.0	14.0	13.5	46.0
		Bottom	26.5	23.0	20.0	17.5	16.5	16.0	14.5	13.0	12.5	52.8
	2	Top	25.8	24.0	21.0	18.2	17.3	15.9	15.1	13.9	13.2	48.8
		Bottom	26.0	23.2	20.5	17.6	16.4	16.0	14.4	13.1	12.4	52.3
	3	Top	26.5	24.3	22.0	19.5	18.3	17.0	15.9	14.0	13.5	49.1
		Bottom	26.6	24.1	21.2	18.8	16.8	16.5	14.8	13.6	12.3	53.8
	AVG	Top	25.8	23.8	21.0	18.6	17.5	16.3	15.3	14.0	13.4	48.0

		Bottom	26.4	23.4	20.6	18.0	16.6	16.2	14.6	13.2	12.4	53.0
		Avg	26.1	23.6	20.8	18.3	17.1	16.2	15.0	13.6	12.9	50.5
T4	1	Top	26.0	25.0	24.0	22.0	21.0	20.0	19.5	19.0	18.7	28.1
		Bottom	26.1	22.6	19.9	17.4	16.0	15.0	14.5	13.8	13.0	50.2
	2	Top	26.2	25.0	24.1	22.0	21.3	19.9	19.5	19.0	18.7	28.6
		Bottom	26.2	22.6	19.9	17.4	16.5	15.0	14.5	13.6	12.7	51.5
	3	Top	27.1	26.0	25.5	24.3	22.0	20.0	19.4	18.5	18.2	32.8
		Bottom	27.3	24.3	20.1	18.6	16.0	14.6	14.0	13.8	13.0	52.4
	AVG	Top	26.4	25.3	24.5	22.8	21.4	20.0	19.5	18.8	18.5	29.9
		Bottom	26.5	23.2	20.0	17.8	16.2	14.9	14.3	13.7	12.9	51.4
		Avg	26.5	24.3	22.3	20.3	18.8	17.4	16.9	16.3	15.7	40.7
T5	1	Top	25.8	24.0	21.0	19.0	18.2	17.0	16.0	15.5	13.5	47.7
		Bottom	26.6	23.5	20.0	18.5	17.0	16.8	16.0	15.0	13.0	51.1
	2	Top	25.6	24.3	21.0	18.7	17.5	16.0	15.5	14.5	13.0	49.2
		Bottom	25.6	23.5	20.0	17.4	16.8	15.8	15.2	14.0	12.8	50.0

	3	Top	26.0	24.2	21.2	18..1	17.4	16.1	15.3	14.4	13.0	50.0
		Bottom	26.2	24.5	20.5	17.2	16.5	15.6	15.1	14.0	12.8	51.1
	AVG	Top	25.8	24.2	21.1	18.9	17.7	16.4	15.6	14.8	13.2	49.0
		Bottom	26.1	23.8	20.2	17.7	16.8	16.1	15.4	14.3	12.9	50.8
		Avg	26.0	24.0	20.6	18.3	17.2	16.2	15.5	14.6	13.0	49.9
T6	1	Top	25.9	25.2	24.0	23.2	22.5	21.3	20.2	18.6	18.1	30.1
		Bottom	26.2	22.0	19.4	16.4	15.3	14.5	13.4	12.8	12.0	54.2
	2	Top	26.0	25.5	24.1	23.0	22.0	21.1	20.0	18.5	18.0	30.8
		Bottom	26.2	22.1	19.0	16.5	15.0	14.0	13.5	13.0	12.0	54.2
	3	Top	26.0	25.5	24.1	23.0	22.2	21.1	20.0	18.5	18.2	30.0
		Bottom	26.1	22.0	19.2	16.5	15.0	14.1	13.5	13.2	11.9	54.4
	AVG	Top	26.0	25.4	24.1	23.1	22.2	21.2	20.1	18.5	18.1	30.3
		Bottom	26.2	22.0	19.2	16.5	15.1	14.2	13.5	13.0	12.0	54.3
		Avg	26.1	23.7	21.6	19.8	18.7	17.7	16.8	15.8	15.0	42.3

Appendix V: Mwea Climatic Data

Nov 2015	Rainfall	Max °c	Min °c	RH(%)	Evp	Dp	Dry	Wet	Dep
1	0	23.3	16.5	84	2	14.2	17	15.3	1.7
2	0	26.4	17	76	3.5	14.8	19	16.3	2.7
3	0	26	17	74	12	14.4	19.2	16.3	2.9
4	0	25.3	16.5	91	5	16.5	18.3	17.2	1.1
5	0	26.3	16	92	4	14.8	16.2	15.4	0.8
6	0	28	17	76	4.5	14.8	19	16.2	2.8
7	0	25.5	17.2	76	5.5	14	18	15.2	2.8
8	0	24	17.5	78	8.5	14.3	17.4	15	3
9	0	26	18	76	4	14.8	19	16.2	2.8
10	0	27	17	90	7	15.1	17.2	16	1.2
11	0	26.3	15	73	6	13.8	18.2	15.2	3
12	0	25.2	17	81	6.5	16.7	20.2	18	2.2
13	0	26.3	16.8	92	7	17	20	18	2
14	0	28.2	14.8	90	6.5	15.4	17.3	16.3	1
15	0	24.2	17.5	75	5	15.6	20.3	17.3	3
16	0	26.4	18	65	5	14.3	17.4	16.2	4.4
17	0	25.3	17.2	90	7	16.2	17.4	16.2	1.2
18	0	25	16.5	90	5	14.4	16.4	15.4	1
19	0	23	17.5	75	3	15.2	20.2	17	3.2
20	0	27	20	76	6.5	16.6	21	18	3
21	0	25.2	18	78	5	14.3	18.3	16	2.3
22	0	24	18.5	83	4	16	19	17	2
23	0	28	21	66	3	15.6	22	17.6	4.4
24	0	28.2	17.5	89	7	15.1	17.4	16.2	1.2
25	0	25.4	19	82	6.5	14.9	18.3	16.3	2
26	2	27	16.5	93	5.5	15.8	17	16.3	0.7
27	0	25	17.5	67	4.5	15.7	22.2	18	4.2
28	0	28	16.5	74	8	14.4	19.2	16.2	3
29	0	29	15.5	61	7.5	16.2	23.3	17	5.3
30	0	29.4	18	70	6.5	18.2	24	20	4
31	0	27.3	17	75	8.5	17.5	22.2	19	3.2
Total	**2**	**811.2**	**535**	**2458**	**179.5**	**476.6**	**591.6**	**516.3**	**78.1**
Mean		**26.1677**	**17.2581**	**79.2903**	**5.79032**	**15.3742**	**19.0839**	**16.6548**	**2.51935**

Appendix VI: Emissions Measurements

i) Test 1

Date 25th March 2019				
Emissions	**CO2**	**CO(ppm)**	**SOX(ppm)**	**NOX(ppm)**
Measuring Time	**%**	**ppm**	**ppm**	**ppm**
9.30	11.0%	75.5	32.2	100.6
10.00	8.0%	42.6	33.0	104.3
10.30	10.0%	50.6	35.1	102.7
11.00	9.0%	69.8	38.3	101.5
11.30	7.0%	77.6	39.4	99.8
12.00	8.0%	72.7	33.5	107.7
Average	8.8%	64.8	35.3	102.7

2) Test 2

Date 26th March 2019				
Emissions	**CO2**	**CO(ppm)**	**SOX(ppm)**	**NOX(ppm)**
Measuring Time	**%**	**ppm**	**ppm**	**ppm**
10.00	12.0	45.0	33	101.5
10.30	11.1%	55.1	35	100.1
11.00	10.0%	67.5	38	98.6
11.30	10.5%	70.4	39	102.6
Average	10.9	59.5	36.3	100.7

3) Test 3

Date 27th March 2019				
Emissions	**CO2**	**CO(ppm)**	**SOX(ppm)**	**NOX(ppm)**
Measuring Time	**%**	**ppm**	**ppm**	**ppm**
10.00	9.2%	43.0	36.0	103.2
10.30	11%	52.0	34.0	104.6
11.00	8.0%	70.6	37.0	102.6
11.30	8.5%	76.5	40.0	100.5
Average	9.2%	60.5	36.8	102.7

Appendix VII: Publications and Conferences

1) Bogonko, N.A. Thoruwa, T., Moturi, M.C.Z. and Makanga J.T.2015

Assessing the Effect of an Exhaust Fan on the Performance of a Rice Husk Fuelled, Flat Bed Paddy Dryer , The International Journal of Science and Technoledge, Vol 8,pp102-106.

2) Paper presented in 2nd Conference of Dedan Kimathi University of Technology (DEKUT) (2nd - 4th Nov 2016) titled, assessing the potential for utilization of rice husks for paddy drying in Mwea irrigation scheme.