DESIGN, DEVELOPMENT AND EVALUATION OF A CONTINUOUS-FLOW MIXING GRAIN DRYER

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ABSTRACT

A low-cost, 250kg to 1-tonne capacity continuous-flow mixing grain dryer (LSU type) was designed and developed. The dryer consists of three main parts: 1) the drying chamber made of inverted V-shaped ducts, to which the plenum inlet is connected; 2) the blower, with a 750 W (1 hp) electric motor and centrifugal fan which provides the drying air; 3) 1 kW electric heater, 4) discharge rollers powered by a 3kW electric gear-motor with a 37.5:1 reduction gearbox. Trials conducted between April and June, 2011 showed that paddy rice, at initial moisture content (MC) of 19.7%- 26.6% dried to 11.8%- 13.5% respectively. Sun drying was also carried out as control.

The drying period for the mechanical drying ranged from 4.8-5.7h and that for sun drying was 5h. The moisture reduction rate ranged form 1.16-2.41%/h for the mechanical drying and 2.18% for sun drying. Milling recovery and head rice yield from mechanical drying were better than for sun drying. The heat efficiencies of drying the four consignments ranged from 36.40%-62.70%. Although power consumption was not measured, the operating cost would reduce if a biomass (rice husk) burner is used instead of electrical energy.

DECLARATION

I hereby declare that this submission is my own work towards the award of Master of Science (Agricultural Machinery Engineering) and that, to the best of my knowledge, it contains neither material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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NOMENCLATURE

Symbol	
MC, mc	Moisture content (%)
wb	Wet basis
db	Dry basis
Rh	Relative humidity (%)
T_a	Ambient temperature (°C)
m_a	Rate of air supply (kg/min.)
q_p	Sensible heat of paddy (kcal)
q_w	Sensible heat of water (kcal)
q_L	Latent heat of water vaporisation (kcal)
w_d	bone-dry paddy mass (kg)
w_w	mass of moisture removed (kg)
q_a	Heat supplied by air (kcal)
ρ_b	bulk density (kg/m^3)
l	length of side of dryer (m)
h_c	height of dryer chamber (m)
V_a	Volume air rate (m^3/min.)

V_e	velocity of in air ducts (m/s)
C_{pp}	Specific Heat of product (cal/g)
C_{pw}	Specific Heat of water (cal/g)
T_{a1}	initial air temperature (°C)
T_{a2}	Final air temperature (°C)
T_{adb}	Ambient dry bulb temperature (°C)
T_{awb}	Ambient wet bulb temperature (°C)
T_{odb}	Outlet dry bulb temperature (°C)
T_i	Inlet dry bulb temperature (°C)
R_g	paddy discharge rate (kg/min.)
V_r	Volume discharge of rollers (m^3)
A	Area (m^2)
b/2	Vertical height of v-duct (m)
L_v	Latent heat of vaporisation (kcal)
m_a	Volume flow rate of air (kg/min.)
D_o	Flute diameter (m)
D_i	Shaft diameter (m)

P	Power (W)
T_q	Torque (Nm)
N_r	Revolutions per minute (rpm)
σ	Compressive stress (N/m^2)
I	Moment of inertia (m^4)
E	Modulus of elasticity (Pa)

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Agricultural processing may be defined as 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 minimise the qualitative and quantitative deterioration of the material after harvest (Sahay and Singh, 2001).

Drying, as part of agricultural processing, is the removal of moisture to a safe moisture content by the application of heat. Drying is practised to maintain the quality of grain during storage to prevent the growth of bacteria and fungi and the development of insects and mites. The safe moisture content for cereal grains is usually 12 to 14% on wet basis (Bala, 1997).

Thus drying is the universal method of conditioning the material by removing moisture to such a level that it is in equilibrium with the normal atmospheric air in order to preserve the quality and nutritive value of the food product and seed quality.

Also, grain drying refers to the removal of some of the moisture from grain by mechanically moving air through the grain after it has been harvested (Wehrspann,1998). Grain in the field dries naturally as the crop matures, giving up moisture to the air until the grain moisture is in equilibrium with the moisture in the air (equilibrium moisture content). Conditions become less favorable for grain to dry to moisture contents considered safe for storage as the harvest is delayed.

1.2 Drying of Paddy rice

Paddy is a hygroscopic, living and respiring biological material. It absorbs and gives off moisture depending upon the grain or paddy moisture content (m.c.), air relative humidity (RH) and temperature of the surrounding atmosphere (Lantin, 2006). As a living biological material paddy respires at an increasing rate with m.c. 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 percent (Lantin, 2006)

Paddy is usually harvested at moisture content of about 24-26 percent (wet basis), higher during the rainy season and lower during the dry season (Lantin, 2006). At this moisture content at 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. This 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 rancid, mouldy, yellowish, and insect and pest infested. Newly harvested grain with high moisture content must therefore be dried within 24 hours to about l4 percent for safe storage and milling or to at most 18 percent (Lantin, 2006) for temporary storage of up to two weeks in case the drying capacity will jeopardize the drying of the rest of the wet paddy and thus get them spoiled. At moisture content of 14 percent or less, wet basis, paddy will be less susceptible to fungal infestations and likely to retain its germination potential. Its shelf life will likely be prolonged and its quality preserved. In wet grain, vapour pressure is high because of the high moisture content. When this grain is subjected to an atmosphere where vapour pressure is low, vapour transfer or movement will occur from high to low until such time that the vapour pressure is the same or the grain is in equilibrium with the atmosphere. Drying therefore is subjecting the grain to an atmosphere of low vapour pressure and providing the necessary heat to vaporise and means to remove the evaporated moisture from the grain (Lantin, 2006). The same is true of moisture movement within the grain. Moisture from the outer surface of the grain is evaporated during drying. Moisture transfer from the core to the grain surface occur s during and after drying until such time that moisture is evenly distributed within the grain. Thus, in sun or solar drying, energy from the sun heat the grain evaporating the moisture and the natural air movement on top of the grain removes the evaporated moisture. Also, in heated air drying, the heat from the drying air vaporise the moisture from the grain and the same drying air removes the evaporated moisture away from the grain. The higher the temperature of the drying air the faster is the drying rate.

Rice is one of the major staple crops in Ghana. The demand for rice in the West African sub-region is growing faster than any other major source of calorie for especially urban dwellers. Local production and processing usually yield rice of poor quality for storage and consumption.

1.3 Why the need of dryers by farmers?

Grains deteriorate due to heavy rains at the time of harvesting. If there is a facility like dryers in every village during this season, this heavy loss may be eliminated.

Normally the problem faced by farmers is that during rainy season grains which are harvested spoil and result in bad quality as they decolorize. Due to this reason, the price is reduced. This loss can be recovered if the dryers are used at this stage.

After drying farmers can store the grains for a long period which will give them good prices. Drying and storing rice on the farm can be an excellent marketing strategy. The way that rice is handled during the drying and storage processes will determine its quality at the point of sale, thereby influencing its value.

Rice should be quickly dried down to a moisture level of about 12 percent for storage, especially if it is going to be stored for several months. The reduction of grain moisture is done by passing relatively large quantities of dry air over the rice after it is place in the bin. The quality and quantity of this air determine the final moisture content of the rice kernel.

1.4 Rice Production and processing in Ghana

Rice is increasingly becoming an important staple food consumed throughout Ghana. Per capita consumption rose from 13.9 kg/y in 1995 to 14.5 kg/y in 2000 (MOFA, 2001), and to 38kg in 2009, as compared to per capita production of 20kg paddy/year or 13kg milled/year (NRDS,2009). Consumption of rice in Ghana has increased tremendously over the last few years and based on population and demand growth rates, had increased to 41.1kg/year milled in 2010 and will increase to 63.0kg/year by 2015, giving a demand of 1 680 000t/year (NRDS,2009). This is mainly as a result of increased urbanization and the relative ease with which it can be cooked. However, the increasing demand for rice (both in quantity and quality) far outweighs local production. Over the past few years, rice production in Ghana has stagnated around 170,000 metric tonnes of milled rice with a self sufficiency ratio of 22% (MOFA, 2005). In addition to this, the quality of the rice produced is variable. To make up for the shortfall, a greater part of rice consumed in Ghana is imported. In the year 2005, figures from the Ministry of Trade and Industry showed that about 600,000 metric tonnes of rice was imported,and increased to about 800,000t/y in 2010 (NRDS,2009). These represented a value of roughly $200 and $266 million respectively, contributing 6% and 8% of Ghana's trade balance deficit in each case. Imported rice is also perceived to be of better quality than local rice and thereby reported to command higher prices. But locally produced rice from industrial mills associated with irrigation schemes is clean, white with a low percentage of broken grain (<10%) and is at par with some varieties of imported rice. Some of this rice is branded, graded and marketed competitively alongside imported rice in Accra markets (NRI, 1997).

Traditional sun drying, which is practiced in Ghana, is weather dependent and harvest seasons sometimes coincide with the rainy season in the southern sector of the country. In order to prevent deterioration after harvest, paddy should be dried down to a level of water activity that will enable safe storage by reducing respiration, inhibiting mould growth and preventing production of mycotoxins. This corresponds to a moisture content of about 13-14%wb, which is considered adequate for safe storage, milling and further storage as milled rice (Hall, 1970). The quality of milled rice, the predominant edible form of rice, is largely determined by the yield of well−milled, whole kernels, referred to in the rice industry as head rice. Broken rice kernels are sold at a much lower price than head rice. Head rice yield (HRY), defined as the percentage weight of rough or unprocessed rice that remains as head rice after milling, is a critical quality parameter used to quantify rice quality, and thus the economic value of rice. HRY is sensitive to production and environmental conditions and can also be dramatically affected by post−harvest processing (Siebenmorgen and Qin, 2005).

The moisture content (m.c.) at which rice is harvested directly affects milling quality, field yield and drying costs. Milled rice, including both whole and broken kernels, is that which remains after the bran has been removed during milling. Head rice denotes milled rice that is comprised of kernels that are three-fourths or more of the original kernel length. The weight of milled rice expressed as a percentage of the rough rice is defined percent milled rice (PMR) while the weight of head rice as a percentage of the rough rice is defined as percent head rice (PHR) (Lu *et al*., 1992).

The reduction in PHR is directly related the fissuring of rice caused by rapid adsorption of water. Early studies by Satel (1935) and Craufurd (1962 and 1963) showed that adsorption of water had no or little effect on rice fissuring when rice m.c. was above 15%. This was further confirmed by other researchers (Srinivas *et al*., 1978; Kamau and Kunze, 1986; Siebenmorgen and Jindal, 1986; Siebenmorgen *et al*., 1992). Craufurd (1962 and 1963) also reported that the adsorption of water vapour by rice with an initial m.c. above 12% did not cause any fissuring, but the presence of liquid water from dew caused rice to fissure. Chen and Kunze (1983) reported PHRs for the long-grain variety 'Labelle' and the medium-grain variety 'Brazos' were not reduced when the 10.7% m.c. rice was remoistened until an environmental relative humidity of 92% was used.

Siebenmorgen and Jindal (1986) found that PHR for the long-grain variety ‘Tebonnet’ was reduced by three percentage points when rice with an initial m.c. of 12% was exposed to a 90% relative humidity environment, the reduction in PHR was less than two percentage points. These studies indicate that a high relative humidity environment does little damage to head rice if the rice m.c. is above 13%. The reduction in PHR in the field is mainly caused by the adsorption of liquid water by rice with an initial m.c. below 15% (Lu *et al*., 2005).

From a technical point of view, drying and milling are the major constraints in the rice processing industry in the southern sector of the country. Widespread introduction of grain dryers will be important in the near future in the country. Although numerous experimental results have been reported on sun-drying of rice in Ghana, no studies on heated-air drying are available in the literature, especially of the new varieties developed. For this purpose, a study of milling properties of heated-air dried rice varieties was undertaken.

1.5 General Objective

The main aim of this project was to design, develop and evaluate the performance of a locally constructed continuous flow-mixing (Louisiana State University, LSU type) grain dryer, to dry 250kg of paddy using locally available materials.

1.6 Specific Objectives

The specific objectives were:

(i) to design and develop a low-capacity continuous flow dryer,

(ii) to evaluate the performance of the dryer.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Drying is the most crucial operation after the harvest of rice (Bakker, 2000). With the advent of the high-yielding and hybrid varieties, which resulted in the high-yielding varieties, meaning harvests being doubled, even trebled, the technology of drying has not caught up (De Padua 1999). Most farmers in Ghana sun-dry their paddy rice either as their first option, or in the absence of another option such as a mechanical dryer, or in avoidance of cash expense for drying. Farmers who have small farm holdings usually dry their harvest on affordable mats which are spread anywhere, or on concrete pavements. Though not all cereal grain is artificially dried, it has been estimated that about 34% of the world's cereal crop is grown in nations where artificial drying is needed for some of the crops (Raghavan *et al*, 2005)

2.2 Thin Layer Drying

Thin layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant conditions of temperature and humidity. Generally, up to 20cm thickness of grain bed (with recommended air-grain ratio) is taken as thin layer (Chakraverty, 2000). All commercial flow dryers are designed on thin layer drying principles (Chakraverty, 2000)

In commercial drying, high-speed fans force the air at right angles across columns of grain about 30 centimetres thick. The columns reduce airflow resistance and allow for more uniform distribution of heat within the grain as the grain moves through the dryer. That's one of the reasons one limits column thickness to 30 to 35 cm (Wilcke and Hellevang, 2002). If the column gets too wide, the moisture and temperature variations across the column get too big. The narrower the column, the smaller those differences are.

2.3 Moisture Content (MC)

Usually the moisture content of a substance is expressed in percentage by weight on wet basis. But the moisture content on dry basis is more simple to use in calculation, as the quantity of moisture at any time is directly proportional to the moisture content on dry basis (Juliano, 1995). Wet basis moisture content is generally used. Dry basis is used primarily in research. (Hellevang, 1995). Rice varieties differ in their critical moisture content (11-16%) below which they fissure readily) and in equilibrium moisture (Juliano, 1995).

2.3.1 Initial Moisture Content (IMC)

One of the factors affecting the energy required for drying grain include the moisture content at harvest and moisture content for storage (Hellevang,1994).

In China, paddy can be harvested at times when rain and high ambient relative humidities can be expected resulting in a harvest with moisture contents in the range 16-18% (Yonglin and Graver, 1995). These may rise to 20-24% in very wet years, causing losses due to moulding and sprouting (Zhuge et al. 1993). In the northeastern and central growing regions, as the crop matures, the grain kernels cease growing and start to dry, with the moisture content of the kernels is still high, around 30-40% (Yonglin and Graver, 1995).

In Indonesia, the situation of IMC is not different, as the harvested moisture content of the paddy in the dry season is about 20-23% wet basis (w.b.) and in wet season is about 24-30% w.b. (Purwadaria, 1995). During the wet season harvest in February-April the price of paddy at 27% m.c. (w.b.) (37% d.b.)is very low (Purwadaria, 1995). He also found out that IMC of 20-27% for paddy and 20-30% for maize are common in Indonesia, Taiwan and Japan.

When rice grains in the field reach harvest moisture (22%), the field sample may contain grains with moisture contents (MC) between 15 and 45% (Kunze, 2008).

2.3.2 Final Moisture Content (FMC)

The importance of final moisture content during drying operations cannot be overemphasized. When rice is exposed to air with high relative humidity (RH), the rice will absorb water from the air i.e. re-wetting (IRRI, 2009). When wet rice is exposed to air with low RH, the rice grain will release water to the air (drying). The equilibrium moisture content (EMC) is the FMC of the grain or seed after being stored for some time with surrounding air of a certain temperature and RH (IRRI, 2009). Final MC, tempering duration, tempering temperature, and drying air temperature have significant effects on HRY (Siebenmorgen *et al*, 2006). Drying considered the varietal differences in critical moisture content (11-16%) below which the grain fissures upon moisture adsorption (Juliano and Perez, 1993). All rice varieties are resistant to fissures at 16% moisture

(Juliano et al. 1993). Low-temperature drying preserves the rice aroma principle, 2-acetyl- I-pyrroline (Itani and Fusilini, 1996).

Improper and over-drying may reduce head rice yield and aroma. Rice varieties differ in their critical moisture content (11-16%) below which they fissure readily and in equilibrium moisture (Juliano, 1995). Thus when the standard FMC is not maintained for a particular grain, overdrying will create fissuring in the grain leading to low HRY. On the other hand, higher FMC will cause deterioration of the grain during storage.

2.4 Dryer Design and development

. Grain breeding programs concentrate on varietal improvement, whereas engineers improve postharvest processes to enhance grain quality (Juliano, 1995) by designing and development. In designing, engineers need to do a whole lot of calculations. Drying experiments are time-consuming and costly; computer simulations require sophisticated models and computation familiarity. A simplified procedure for the capacity calculation of batch-in-bin and cross-flow grain dryers has been developed by making a number of simplifying assumptions in the heat and mass transfer equations (Qiang and Bakker-Arkema, 1998). The calculations require only a hand calculator and a psychrometric chart. Dryer-capacity data computed with the new procedure are within ± 10% of those obtained experimentally or those calculated by computer simulation (Qiang and Bakker-Arkema, 1998). The method provides a simple and rapid procedure to predict the effect of the drying temperature and the airflow rate on dryer capacity. In dryer design, one of the objectives was to develop a *simplified* procedure for calculating dryer capacity. The procedure should be accurate to ± 10%, should only need a calculator and some graphs, and should be simple to implement (Qiang and Bakker-Arkema,1998) .

The development of a simplified capacity-calculation procedure of a complicated process often requires that some simplifying assumptions are made which scientifically cannot always be justified but which are *pragmatically warranted* because they lead to *useful results.* Batch-in-bin and cross-flow dryer types are modeled by similar systems of four differential equations (Qiang and Bakker-Arkema, 1992.)

Design and manufacture of mechanical dryers in China commenced in the late 1950s utilizing Russian design, theory, and engineering principles (Yonglin and Graver, 1995). The late 1970s and early 1980s were years of successive bumper crops, which created an immense grain drying problem. This situation produced the impetus to develop and extend the application of mechanical drying, which has since continued rapidly. Nowadays, most grain dryers are designed and manufactured by provincial engineering research and design institutes, or end users (Yonglin and Graver, 1995). Design calculations have been carried out to minimise fissuring during mechanical drying of rice (Bakker-Arkema et a1. 1998). Following the success of the development of the cross-flow fluidized bed paddy dryer, Rice Engineering Supply Co. Ltd., a private company in Thailand, showed interest in collaborating in the development of a prototype with a capacity of approximately 1 t/h (Soponronnarit et al., 1995). As a result of the success of the prototype, commercial fluidized bed paddy dryers with capacities of 5, 10 and 20 t/h were installed, and more than 200 units have been sold since the beginning of 1995.

2.5 Types of Mechanical Dryers in use

Major types of hot air dryers are designed as bin, batch and continuous flow (Wilcke and Hellevang, 2002). There are various versions of the above three types of dryers in use globally. Three types are commonly used in China: tower dryers, rotary drum dryers, and fluidized-bed dryers (Wang 1986; Zhang 1988). Fluidized-bed dryers are popular in the southern growing area for drying paddy (Zhao Simong ,1996). These dryers operate at high temperatures and are fuelled with rice husks or coal. However, grain residence time within fluidized-bed dryers is short- approximately 2 minutes. In addition, because the grain is well mixed with the drying air during the fluidizing process, the capacity of such dryers is greater, ranging from 3-5 t/h. They are capable of reducing grain moisture content by 3-5% per pass (Zhao Simong, 1996).

Sutherland and Ghaly (1992) were probably the first research group who investigated the feasibility of using fluidization technique for paddy drying. Experimental results reported by Sutherland and Ghaly (1992) showed that head yield was 58-61% when paddy was dried from 28.2 to 20.5%. Soponronnarit and Prachayawarakorn (1994) reviewed the research and development work on fluidized bed drying of grain, and conducted both experimental and simulation studies on batch fluidized bed drying of paddy. They described the development of a cross-flow fluidized bed paddy dryer with a capacity of 200 kg/hour. Experimental results showed that final moisture content of paddy should not be lower than 23% if quality in terms of both whiteness and head yield were to be maintained. Drying air temperature was 115°C.

One of the most conventional methods of drying is deep bed type. In this type of dryer, grain drying is considered as batch process where moisture content, air and grain temperature, and the humidity of the air change simultaneously (Sitompul *et al.*, 2001).

Continuous dryers are usually characterized by the relative directions of flow of grain and air, i.e. cross flow, concurrent flow, counter- flow and mixed-flow (Parry, 1985). Generally, drying of grain requires exposure to an atmosphere of lower relative humidity than the equilibrium value at the grain surface. This can be arranged by flowing a hot gas of low relative humidity around the grain, usually in the bed of grain. (Sitompul *et al.*, 2001).

Off-farm dryers are considered to be of the high- temperature continuous-flow type, and to have a capacity of at least 12.5 t/h. Usually, this excludes all but the largest in-bin drying systems.

The main off-farm dryer types are: (1) the *cross- flow* dryer, (2) the *mixed-flow* dryer, and (3) the *concurrent- flow/counter-flow* dryer (Bakker-Arkema and Maier, 2002). Each dryer type has specific advantages and disadvantages. The dryer- selection criteria differ somewhat from country to country, and from crop to crop.

The in-bin dryers, use ambient air with or without supplemental heat. There are also combinations of in-bin and continuous flow dryers, developed within the concept of two- stage drying (Srzednicki, 2005). In a two-stage drying system grain is dried using a high-temperature fast dryer down to a moisture content of about 18% wet basis (w.b.), and then down to a safe storage moisture content (generally 14% w.b.) in an in-bin dryer using near ambient air. The latter is called an in-store dryer since grain will be stored after drying in the same bin or store (Srzednicki and Driscoll 1994). During extended storage, grain will usually also be aerated in order to further reduce the risk of deterioration. (Srzednicki, 2005)

Continuous-flow high-temperature dryers are used for drying large quantities of grain, generally in several passes, from field moisture down to at least 18% w.b. moisture content. This is a continuous operation involving grain of different initial moisture contents and therefore requiring appropriate adjustments of the residence time. The main types of continuous- flow dryers used in the grain industry are cross-flow, concurrent-flow, counter-flow and mixed-flow
(Srzednicki, 2005)

In Indonesia, commercial mechanical dryers in operation, and their performance, are the locally manufactured types commonly coming as flat bed, circulating and continuous-flow types (ACPHP,1988;Purwadaria,1995). In America, dryer manufacturers are reporting a renaissance in sales of high-speed, continuous flow dryers (Werhspann, 1998). Continuous flow dryers can handle moisture levels as high as 25 and 30%. In-bin systems cannot handle those moisture levels as easily (Werhspann, 1998).

2.6 Maintaining Grain Quality during Drying by:-

Grain quality during drying can be maintained by:

(i) Dryer Type

Bakker-Arkema *et al* (1998) have recently investigated the effect of dryer type on maize quality (Montross et al., 1994; Liu et al., 1994). In the USA, three dryer types were tested, i.e. cross-flow, concurrent-flow and mixed- flow models. In China, the same three types were investigated, along with steam-drying and sun-drying installations. They found out that:

I. Sun drying is able to produce maize with a minimum number of stress cracks *if properly implemented.*

2. Steam-dried maize usually has only a small number of stress cracks.

3. Of the three major high-temperature dryer types, concurrent-flow dryers cause the smallest increase in the number of stress cracks in maize kernels while cross-flow dryers generate the largest increase.

4. Mixed-flow dryers fall between the concurrent- flow and cross-flow dryer types with respect to the stress-cracking of maize.

IRRI (2007), in its research observed that it is not possible to dry paddy in a continuous flow dryer from typical MC down to levels for safe storage in one single pass. Typical drying m.c reduction rates per pass are around 2%. One pass lasts 15 to 30 minutes at around 70ºC drying air temperature. Higher rates could be achieved by increasing either the drying air temperature or the retention time but both would negatively affect grain quality because of increased cracking. Continuous flow drying systems are therefore operated as multi-pass systems where the grain is moved to tempering bins from 6 to 24 hours after each pass until the desired m.c is reached (IRRI, 2007) *(ii) Drying Temperature*

The *drying-air temperatures* employed in high- temperature grain dryers depend on the dryer type and the grain variety. From values of temperatures measured recently in maize dryers at elevator/grain-depot sites in the USA and China (Montross *et al.* 1994; Liu et al. 1994), it was clearly evident that the concurrent-flow dryers operate at the highest temperature, the cross-flow dryers at the lowest temperature. The disparity in operating temperatures between those measured in the USA and China is due to the different heat sources used in the two countries: natural gas in the USA, coal in China.(Bakker-Arkema *et al.*,1998)

(iii) Dryer Control

The moisture content of wet grain reaching a high- temperature continuous-flow dryer over a 24-h period can vary greatly. This is due to the different harvest procedure preferences, soil types, and variety selections of individual farmers. At commercial dryers, it is not unusual to encounter moisture content differences of 10-15% in lots of maize received from different growers (Bakker-Arkema *et al.*, 1998). Yet all the grain must be dried to approximately the same average moisture content. The challenge presented to the dryer operator or the automatic controller, is to properly vary the speed of the unloading auger and thus the residence time of the grain in the dryer.

Manual control of continuous-flow dryers often leads to significant overdrying or underdrying. Automatic control of continuous-flow dryers is usually designed to minimise these occurrences. Secondary objectives are minimising energy consumption and optimising dryer capacity, both necessarily subject to grain quality constraints (Eltigani and Bakker- Arkema 1987).

(iv) Air Flow Rate

The 'specific' air flow rate is the quantity of air passing through a grain mass divided by the volume of grain it passes through (e.g. measured in litres of air per second per tonne of grain, or m^3 /min/m^3 (Newman, 1990).

Newman (1990) observed that as the air passes through the grain mass, the specific airflow rate becomes smaller and smaller, until it reaches a minimum value at the surface of the grain. It is this minimum value of specific flow rate that governs the drying performance of a system, since it defines the time that it takes for drying the grain mass.

Thus, the minimum specific airflow rate governs the speed of the 'moisture front' in grain drying. Estimating the speeds of this front depends on a number of factors, the principal factors being - apart from the physical properties of the grain-the temperature and moisture of the grain and of the air being passed through it.

(v)   Drying Rate

The drying rate is defined as the rate at which grain moisture content declines during the drying process. It is normally expressed in percent moisture removed per hour [%/hr]. Typical drying rates of rice dryers are in the 0.5%/hr to 1%/hr range (IRRI, 2009). The drying rate is not constant but changes over time. The temperature of the grain equally changes over time. The rate of sun drying (0.3-0.5% m.c dry basis/hour) is lower than all mechanical drying (1.1-1.9% m.c. dry basis/hour).

In drying high-moisture rough rice with heated air, drying starts from the surface of the kernel and progresses inward (Abe *et a.*, 1992). They stated in their study that drying too rapidly causes "case hardening" whereby the surface of the grain dries out rapidly, sealing the moisture within the inner layers. The internal pressure thus developed causes cracks to develop. They concluded that the same phenomenon accounts for the development of chalky grains. Drying rate generally increases with increasing moisture content of grain and air temperature or decreases with increase in air humidity (Trim and Robinson, 1994). Chakraverty (1994) genralised the factors that affect drying rate as temperature, air flow rate, relative humidity, exposure time, types, variety and size of grain, initial moisture content and grain depth. Drying air temperature was found to have the greatest effect on drying rate, followed by air velocity and then initial moisture content. Relative humidity had the least effect of all and was not included in their model development (Hustrulid, 1962, 1963).

2.7 Thermodynamics Properties of Grain Drying

Physical testing of the thermodynamic performance of grain dryers is necessary to improve prototypes, to confirm their specification and to provide information for marketing and operator guidance (Nellist and Bruce, 2005)

The importance of accurate determination of moisture content and of the difference between input and output moisture levels was demonstrated by Nellist and Bruce (2005). The basic physical and thermodynamic properties of grain and air were examined, and the theory of the drying process was developed. Designs of the optimum operating conditions were recorded for all who were interested in the proper drying and storage of grain (Brooker *et al.*, 1992).

In monitoring the performance of a commercial batch grain dryer under real operating conditions while drying barley Guangnan and Zare (2009) measured the distribution of key drying parameters of air temperature, relative humidity, airflow, grain moisture content, drying time and energy use. For the two trials they conducted, the overall cycle-averaged process thermal efficiency was 48·4 and 41·5%, respectively. This ws achieved when the average initial moisture contents of the grain were, respectively, 15·7 and 17·2% and the highest plenum temperatures 41·4 and 34·0°C (Guangnan and Zare, 2009).

2.7.1 Humidity Ratio of Air:

Humidity ratio (grains of moisture per pound of dry air , GPP) is the ratio between actual mass of water vapour present in moist air, to the mass of dry air. Humidity ratio can be expressed by mass of water or by the partial vapour pressure in the moist air. (Hardy, 1998)

Humidity Ratio by Mass:

Humidity ratio can be expressed as the ratio between the actual mass of water vapour present in moist air- to the mass of the dry air (Hardy, 1998). Humidity ratio is normally expressed in kilogram water vapor per kilogram dry air (Hardy, 1998).

$X = m_w / m_g$ . . . . (1)

Where X = humidity ratio (kg H_2O / kg dry air)

m_w = mass of water vapor (kg)

m_g = mass of dry air (kg)

Humidity Ratio by Vapor Partial Pressure

Humidity ratio can also be expressed with the partial pressure of water vapor (Hardy, 1998)

i.e. $$X = \frac{0.62198 p_w}{p_{atm} - p_w} \quad \ldots\ldots (2)$$

where X = humidity ratio (kg water /kg dry air)

p_w = partial pressure of water vapor in moist air (Pa),

p_{atm} = atmospheric pressure (101325Pa)

or as recommended by Cengel and Boles (2002)

$$X = \frac{o.622 x Rh x P_s}{P_{atm} - Rh x P_s} \quad \ldots\ldots (3)$$

Where Rh = Relative humidity of air (%)

P_s = Saturation Pressure at T (Pa)

P_{atm} = atmospheric pressure = 101325 Pa.

Humidity ratio by vapor partial pressure is the type selected to be used by this study.

In the graphical representation of Humidity Ratio versus temperature, Hardy, (1998) showed that the saturation pressure of water vapor, and the maximum humidity ratio increase dramatically with the air temperature. This is important for the drying process.

2.7.2 Enthalpy of Moist and Humid Air

The enthalpy of moist and humid air consists of sensible heat and latent heat. Enthalpy is used to calculate cooling and heating processes.

Moist air is a mixture of dry air and water vapor. In atmospheric air, water vapor content varies from 0 to 3% by mass (Cengel and Boles, 2002). The enthalpy of moist and humid air includes:

- Enthalpy of the dry air- the sensible heat, and
- The enthalpy of the evaporated water- the latent heat.

Specific enthalpy, h (J/kg) of moist air is defined as the total enthalpy (J) of the dry air and the water vapor mixture per unit mass (kg) of moist air (Cengel and Boles, 2002).

Thus enthalpy, $h = 1.005\,T + X\,(2501.3 + 1.82T)$ . . . .(4)

Where h = enthalpy (kJ/kg)

X = Humidity ratio

T = Dry bulb temperature (°C)

2.7.3 Saturation Pressure

Water Saturation pressure of water in N/ m^2 (Pa) is given by Hunter (1987)

Saturation pressure, $P_s = \frac{6 \, x \, 10^{25}}{(T + 273.15)^5} \exp[\frac{-6800}{T + 273.15}]$, ...(5)

Dakpa *et al* (2009) in the performance evaluation of a locally fabricated dryer had an average dryer efficiency of 70%, an average specific heat consumption of 1726kJ/kg H_2O which was equivalent to 0.48kWhr/kg H_2O. When 50% exhaust air was circulated, inlet humidity ratio increased by46.1% and enthalpy by 50.5%.

2.7.4 Drying Efficiency

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. There are three groups of factors affecting drying efficiency:

* those related to the environment, in particular, ambient air conditions;

* those specific to the crop

* those specific to the design and operation of the dryer.(FAO, 2002)

There are several different ways of expressing the efficiency of drying, of which the sensible heat utilization efficiency (SHUE), the fuel efficiency, and the drying efficiency are the most useful.

The SHUE takes into account the sensible heat attributable to the condition of the ambient air and any heat added to the air by the fan as well as the heat supplied by combustion of the fuel FAO, 2002). It is defined as:

$$\text{SHUE} = \frac{Heat\ Utilized\ for\ Moisture\ Removal}{Total\ Sensible\ Heat\ in\ the\ Drying\ Air} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

SHUE is also called Heat Utilisation Factor H.U.F. (Chakraverty, 2000), which can be defined as the ratio of temperature decrease due to cooling of the air during drying and the temperature increase due to heating of the air. Thus H.U.F. =

$$\frac{Air\ temperature\ decrease\ during\ drying}{Air\ temperature\ increase\ during\ heating} \quad \ldots\ldots\ldots\ldots (7)$$

$$= \frac{Heat\ utilized}{Heat\ supplied}$$

$$= \frac{T_1 - T_2}{T_1 - T_0}$$

Coefficient of Performance (COP):

The coefficient of performance, COP (Cengel and Boles, 2002) of a grain dryer is expressed mathematically as follows:

$$\text{C. O. P.} = \frac{T_2 - T_0}{T_1 - T_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where T_2 = dry bulb temperature of exhaust air

T_1 = dry bulb temperature of drying air

T_0 = dry bulb temperature of ambient air.

The drying efficiency, defined as:

$$\text{Dryer Efficiency} = \frac{Heat\ Utilized\ for\ Moisture\ Removal}{Heat\ Available\ for\ Moisture\ Removal} \quad \ldots\ldots\ldots\ldots (9)$$

is the expression to be used for evaluation of dryer designs or comparison between dryers, since it is a measurement of the degree of utilization of the sensible heat in the drying air.

The drying efficiency, also known as effective Heat efficiency (E. H. E.), (Chakraverty, 2000) considers the sensible heat in drying air as being the effective heat for drying, i.e.

$$\text{E. H. E.} = \frac{T_1 - T_2}{T_1 - T_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where T_w = wet bulb temperature of drying air.

Foster (1973) evaluated the fuel and drying efficiencies of several types of dryers used with maize. Over a wide range of conditions, continuous-flow dryers were found to have a fuel efficiency of 38% and a drying efficiency of 51%, batch dryers 42% and 58%, dryeration 61% and 78%, and two-stage drying, 60% and 79%, respectively (FAO, 2002)

2.8 Milling and Headrice Recovery

Milling and headrice recovery are important criteria in assessing the quality of the paddy rice, which is greatly influenced by drying. Headrice recovery is the percent headrice ratio of the weight of grains that do not break in the process of milling and with the size of ¾ or more of the whole grain, to the total weight of milled rice, expressed in percent (Ulep *et al., 2005)*

Milling is a crucial step in post-production of rice. IRRI (2009) says that the basic objective of a rice milling system is to remove the husk and the bran layers, and produce an edible, white rice kernel that is sufficiently milled and free of impurities. Depending on the requirements of the customer, the rice should have a minimum of broken kernels.

Most rice varieties are composed of roughly 20% rice *hull* or *husk*, 11% *bran* layers, and 69-% *starchy endosperm*, also referred to as the *total* milled rice. In an ideal milling process this will result in the following fractions: 20% husk, 8-12% bran depending on the milling degree and 68-72% milled rice or white rice depending on the variety. Total milled rice contains *whole grains* or *head rice*, and *brokens*. The by-products in rice milling are rice hull, rice germ and bran layers, and *fine brokens*. Rough rice is also called paddy rice as it comes from the field. Rice kernels are still encased in their inedible, protective hull. The following are definitions by IRRI (2009) :-

Milling recovery: Total milled rice obtained out of paddy; expressed as weight percentage of milled rice (including brokens) obtained from a sample of paddy. The maximum milling recovery is 69-70% depending on rice variety, but because of grain imperfections and the presence of unfilled grains, commercial millers are happy when they achieve 65% milling recovery. Some village type milling achieve 55%. *Head rice* *recovery:* Weight percentage of head rice (excluding brokens) obtained from a sample of paddy. Under controlled conditions head rice recovery can be as high as 84% of the total milled rice or 58% of the paddy weight. Commercial rice mills turn out 55% head rice on average, whereas head rice recovery of village type rice mills is in the order of 30%. IRRI (2007) described the following categories as large broken kernel: 50-75% of the whole kernel size; medium broken kernel: 25-50% of the whole kernel size ; small broken kernel: less than 25% of the kernel size, can not pass through a sieve with 1.4mm diameter holes; chips: fragments of a kernel which pass through a sieve with 1.4mm diameter holes.

Studies conducted in Thailand and Cambodia (Yasuo, 2003) showed that the cost of drying in both countries is equivalent to 4% of the total paddy production cost. All the dryers that were successfully commercialized in Vietnam have drying cost with less than 5% of the paddy value (Hien, 1998). Case studies in other Asian countries indicate that mechanical dryers with cost higher than 5% of the paddy value cannot be introduced successfully (IRRI, 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction (background information)

The continuous flow-mixing grain dryer design is a duct type and this is a significant factor which leads to its high energy efficiency and high grain quality reputation. In this type of dryer design the grain and air move generally in the same direction. This is referred to in the business, as a concurrent flow design (Excel Grain Dryers, 2007). Figure 3.1 illustrates the grain-flow versus air flow pattern. It is obvious that the grain stream flows from top to bottom under the influence of gravity. Notice that the hot drying air gets into the grain mass at the top of every 40cm tall tier section and flows with the grain, heating it up and removing moisture, until an exhaust duct is readied which is at the bottom of each tier section. A certain percentage of the drying air goes upward and to the left and right to exhaust ducts, so some authors refer to this as a mixed flow type dryer (GSI, 2011).

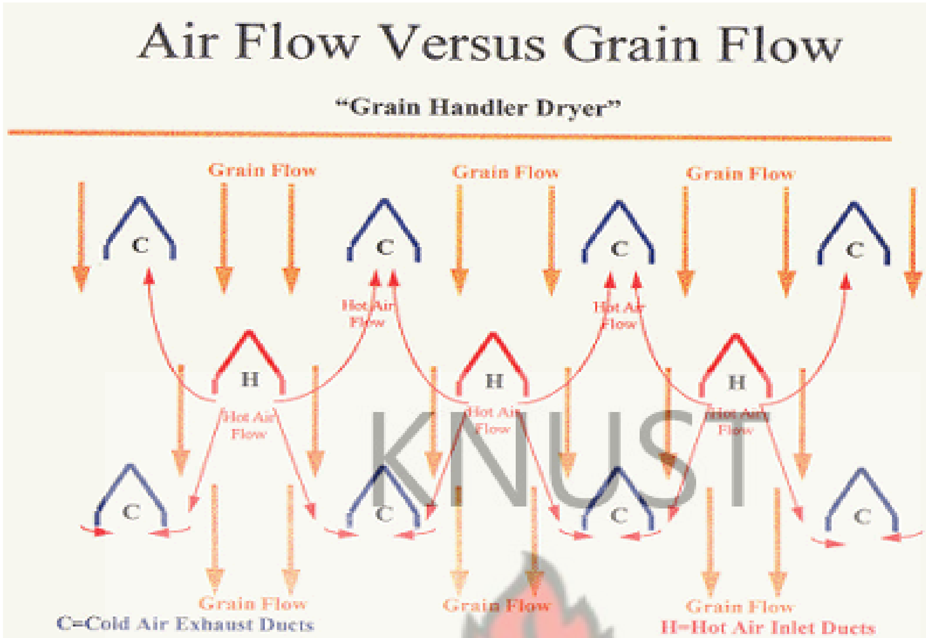

Fig .3.1Grian and air flow patterns in the dryer. (Grain Handler, 2004)

Fig. 3.1 illustrates the fact that each grain column in the **dryer** is a cavity which is "honeycombed" with ducts for delivery of hot air (top of tier section) and exhaust of moist air (bottom of tier section). The inlet ducts are open to the hot air plenum but are capped at the outside of the dryer. Alternately, the exhaust ducts are capped on their plenum end but open to the ambient environment in order to exhaust moisture laden air. This duct arrangement provides for the mixed air/grain flow pattern and also tumbles the grain continuously which contributes to even drying and no drying front like screen dryers.

The energy efficiency derives from the fact that we have concurrent, counter-concurrent and cross air/grain flow patterns which allow for more complete heat energy transfer from the drying air to the grain mass than possible from simple cross flow type dryers (screen dryers) (Excel Grain Dryers, 2007) . The grain quality superiority derives from the constant tumbling of the grain and from the low energy delivery rate similar to natural drying. Research has addressed the subject of grain quality as a function of the type of dryer air/grain flow pattern (Excel Grain Dryers, 2007).

3.2 Materials for construction

The main materials for construction of the dryer are: 70x70mm angle iron; 2mm mild steel plate; 1mm mild steel plate; 40x40mm angle iron; 12mm bolts and nuts; 35mm bore bearings; gearbox; sprockets; pulleys; belts.

Others are: paddy rice, thermometers, 0.75 kW air blower, 1000W electric heater, conductance moisture meter, 3kW speed reducer.

3.3 Method

3.3.1 Design of the dryer

3.3.1.1 Design Considerations

The purpose of the continuous –flow mixing dryer is to eliminate the difficulties of drying of grains, especially paddy rice.

Hundreds of millions of tonnes of wheat, corn, soybean, rice and other grains such as sorghum, sunflower seeds, rapeseed/canola, barley, oats, etc., are dried in grain dryers. In the main agricultural countries, drying comprises the reduction of moisture from about 17-30%w/w to values between 8 and 15%w/w, depending on the grain. (Excel Grain Dryers, 2007)

Ghana consumes some 1,064,000 tonnes of rice per year and currently produces 30% sufficient to satisfy this demand (Ghana rice,2009).

Individual production is on a very small scale and it is also extremely widespread, especially in remote areas and are normally clustered in farm units (Ghana Rice, 2009).

Mechanical grain dryers like this one perform the drying action, based upon the moisture content of the rice, 17 to 30% (w.b), input heat, ambient temperature and relative humidity.

Rice drying is carried on by farmers on concrete floors or on mats. During the drying season, this is easily done within some few days, but during the rainy season, this becomes a problem since sunshine is shielded by cloudy skies and frequent rains.

As an expert on dryers, Wehrspann (1998) observed that cross-flow (screen) dryers by nature of design do not treat all seeds equally. Critical temperature on some seeds is exceeded as need for capacity with small retention time requires high heat. The result is crackage and overall quality reduction. Some crops simply cannot tolerate this style of drying, limiting the flexibility of this type of machine (Excel Grain Dryers, 2007).

Mixed-Flow Dryers

Three important factors occur as grain move from top to bottom in a continuous-flow mixing dryer: grains are gently mixed and stirred as they flow over the ducts smoothing the front to back variations within the machine; grains pass through alternating horizontal heat zones removing surface moisture in hotter zones while allowing time for moisture in cooler zones; grains pass through alternate regions of air patterns, switching drying characteristics as each concurrent and counter flow region is encountered. The combination of these factors guarantee that each seed is treated gently, equally and properly handled without stress or damage. This translates to the highest possible quality on the widest variety of products. Features that are unique to the continuous flow driers are user friendly, and robust ,curved duct cutout for strength , no screens to clean, large holding capacities, duct design allows drying of all types of grain, continuous flow or batch dry capabilities (Excel Grain Dryers, 2007) , cleans the grain of dust and light impurities while recirculation, knock-down design for fast installation (1-day), no need for excavation or any other modification on site, fits inside standard 6 meter warehouse, single-phase 220V power source (optional 3-phase), simple design and made of locally available materials, saves more than 50% in drying cost using biomass fuel, available in 1 - 20 tons per batch model.

3.3.1.2 Design Concept and criteria

The synthesis of a scheme, in this case the grain dryer, connecting possible system elements is sometimes called the *design concept*. This is the first and most important step in the synthesis task.(Nisbett , 2008). The dryer design was broken into various elements, so that each can be considered separately in the design.

It was planned that the dryer will have inverted v-ducts, duct supports, corner supports, discharge rollers, shafts, bearings, bottom hopper, speed reducer, plenum, electric heater elements, blower, electric- gear motor, washers, bolts and nuts, drive chain, sprockets, pulleys, v-belts,

The *design criteria* considered the mechanical dryer for paddy rice and other grains and the following features for it were to be borne in the design, i.e. design for strength, simplicity, reliability, cost effectiveness, ease of maintenance, ease of operation, safety and usability (Aikins, 2009)

3.3.1.3 Design Equations of the dryer

(i) Strength of materials equations (See Appendix II for detailed Calculations)

In general, the work done by a torque T_q of constant magnitude is given by

$$W = T\psi \quad \text{where} \quad \psi = \text{angle of rotation in radians}$$

If power, P is the rate at which work is done, then $P = \frac{dW}{dt} = T\frac{d\psi}{dt}$

Now $\frac{d\psi}{dt}$ is the angular speed ω . Therefore P = Tω (ω is in rad/s)

If rpm denoted by $\boldsymbol{n_r}$ then P = Tω = $\frac{2\pi n_r}{60}\boldsymbol{T}$, from which torque,

$$T_q = \frac{60P}{2\pi n_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

The rollers have diameter d , and the resistance offered by the paddy, R is given by

$$R = \rho_b g\, v = \frac{2\pi d^2 l}{4}\rho_b g$$

The work done by the resistance offered by the paddy rice is

$$W_r = R \times d/2 = \frac{2\pi d^3}{8} l\rho_b g \quad \ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Thus (i) and (ii) can be compared.

Buckling of the 70 x 70 angle irons at the four corners of the dryer:

From the secant formula for eccentric loading of columns, the maximum compressive stress on the corners is given by (Gere, 2004)

$\sigma_{max} = \frac{P}{A}\left[1 + \frac{ey}{r^2}\sec\left(\frac{l}{2r}\sqrt{\frac{P}{AE}}\right)\right]$ …..(i) where, P = force (load) on the members,

A = cross-sectional area

e = eccentricity

r = radius of gyration, = $\sqrt{[\frac{I}{A}]}$

l = original length of column

E = modulus of elasticity,

y = dist. From neutral axis to the outer fibre of column

Properties of equal leg angle iron:

Moment of inertia,

$$I = \frac{A}{12} [7 (a^2 + b^2) - 12y^2] - 2ab^2(a - b)$$

Distance from neutral axis to the outer fibre of column, (Gere, 2004)

$$y = \frac{a^2 + at - t^2}{2 (2a - t) \cos 45°}$$

where A = cross-sectional area = t (2a - t)

a = cross-sectional length of side of angle iron

t = thickness of angle iron

b = a – t

Chain drive:

The length of the chain is given by,

$$L = 2C + \frac{N+n}{2} + \frac{(N-n)^2}{4\pi^2 C}, \quad \text{(PTD, 1998)}$$

Where C = distance between the centres of the sprockets. Also, C can be given by(PTD, 1998)

$$C = \frac{1}{4}\left[L - \frac{N-n}{2}\sqrt{\left[L - \frac{N+n}{2}\right]^2 - \frac{8(N-n)^2}{4\pi^2}}\right],$$

N = number of teeth on the larger sprocket

n = number of teeth on the smaller sprocket

Belt drive:

Length of belt is given by, $L_b = 2C + 1.57\,(D + d) + \frac{(D-d)^2}{4C}$,

(ii) Dryer capacity, process and operating equations

See Appendix II for Dryer Capacity Design Calculations

Bone-dry paddy mass, $w_d = (1 - mc_{wb})$

Mass of moisture removed: $w_w = w_d\ (mc_1 - mc_2)$

Heat supplied by the drying air: $qa = (0.24 + 0.45H)\, m_a\ (T_{a1} - T_{a2})$

Sensible heat of grain: $q_p = w_d\ Cpp\ (T_{p2} - T_{p1})$

Sensible heat of water: $q_w = m_w\ C_{pw}\ (T_{p2} - T_{p1}) = w_d\ mc_1\ C_{pw}\ (T_{p2} - T_{p1})$

Volume of dryer, V = $\frac{\boldsymbol{m}}{\boldsymbol{\rho_b}}$ = $L^2 h_c$ - $\frac{v_a}{v_e} L$

Air duct area, A = $\frac{\boldsymbol{b^2}}{\boldsymbol{4}}$

Discharge rollers volume, V_r = $\frac{\pi}{4}$ (D_o^2 - D_i^2) L

Required roller speed, ω = $\frac{Grain\ discharge\ rate}{Wt\ of\ paddy\ discharged\ by\ rollers}$ = $\frac{R_g}{V_r \rho_b}$

Blower Power, P = $\frac{\Delta p m_a}{4500}$ = 0.75 kW

3.3.2 Construction of the Continuous-flow mixing Dryer

See Appendix I for detailed drawing of parts, and the sketch of the dryer below, Fig.3.1

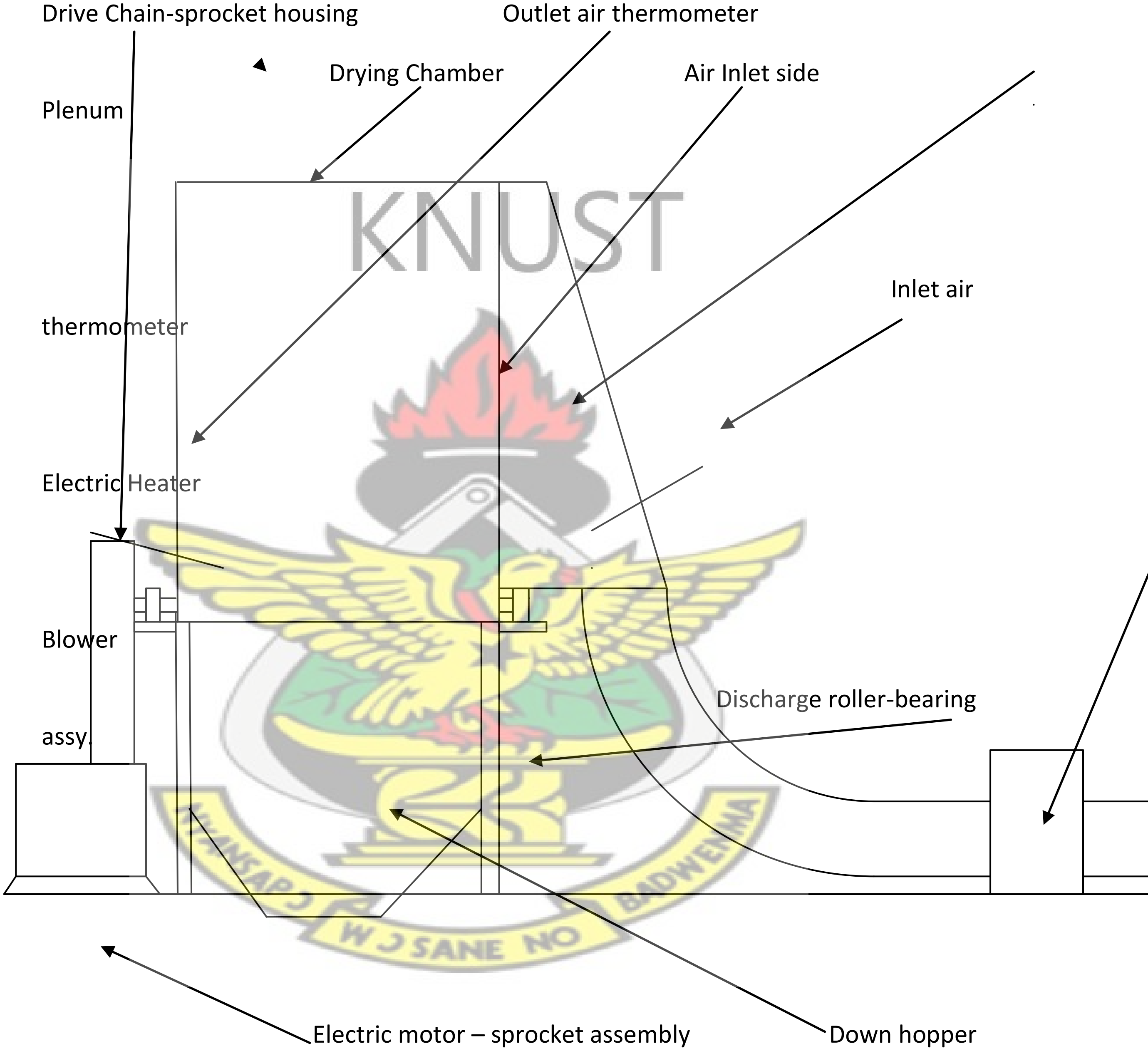

Fig. 3.2 Sketch of Dryer assembly.

The workshop processes used in the construction of the dryer are marking, cutting, drilling, bending, rolling, grinding, turning, fastening, welding, filing, milling and shaping.

The dryer parts were marked out using a steel tape measure and a scriber. A machine saw was used to cut all the angle sections and round bar to size. A centre punch was used to punch all the points where holes are to be drilled, and a pedestal drilling machine was used to drill all the holes. Three 2.40 m x 1.20m x 2mm mild steel plates were cut into 0.9m x 0.28 x 2mm pieces and these bent at 90° to form the inverted v-ducts. Also, 1mm thick plates (4 no.s) were cut to size, and triangular holes were cut through them according to the spacing of the alternating nature of the inlet and outlet ducts. The bolt and nut fastenings done so far use M12 bolts, nuts and washers.

3.3.2.1 The stand frame

Four members of cut 70 x 70 mm angle iron of height 1.0 m were used for the stand and were welded at the bottom with four rods, at 0.9m apart, forming a square cross-section as in the isometric view shown. Then two bearing seats, 70 x 70 mm angle iron pieces of length 0.9m were fastened with bolts and nuts to two opposite sides of the square cross-section formed initially. Three discharge roller assemblies and three pairs block bearings were subsequently fixed onto the bearing seat , and then an air outlet subassembly was fastened on top of the bearing assembly to complete the stand bearing roller frame assembly.

3.3.2.2 Roller shafts and Discharge rollers subassembly

A centre lathe was used to turn the roller shafts and were welded to the 70 x 70 mm angle irons turned at the 90° to each other to form the roller-shaft assembly.

3.3.2.3 Air outlet duct subassembly

Two inverted v-ducts and two half duct pieces were arranged and welded on two 40 x 40 mm angle iron pieces, forming a 0.9 m x 0.9m square frame. That is the air outlet duct assembly.

3.3.2.4 Air inlet duct subassembly

Three inverted v-ducts were arranged and welded on two 40 x 40 mm angle iron pieces, forming a 0.9m x 0.9m square frame. This is the air inlet duct assembly.

3.3.2.5 Drying chamber subassembly

Four 70 x 70 mm angle iron sections, with holes drilled at 20cm interval were arranged, forming a 0.9 x 0.9m square, and the air inlet and outlet subassemblies were fastened by bolts, nuts and washers alternately, with the air inlet subassembly going first at the bottom for the whole height of 2.5m. This assembly was done to ensure that all duct subassemblies were fitting well. They were dismantled and put down for the final assembly.

3.3.2.7 Final assembly

The bearing roller stand subassembly was positioned at a vantage point in the room, and the four drying chamber corner angle irons (70x70mm x2.5m) were fastened to the four corner angle irons of the stand assembly previously drilled holes for that purpose, using M12 bolts, nuts and washers. Then an air inlet duct assembly was fastened at the bottom, followed by outlet one, alternately like that to the top. Then four 1mm plates were used to cover the sides, with the air inlet plate to the plenum side, and the outlet one to the air discharge side.

3.3.3 Dryer Evaluation (See Appendix IV for evaluation data)

Technical performance of the dryer was verified during actual drying tests at the Agric. Engineering workshop, KNUST, Kumasi after the harvesting of paddy in the surrounding growing areas of Nobewam and Besease, both in the Ashanti Region of Ghana, in the months of April, May and June, 2011.The parameters measured during the actual drying tests were: drying and ambient air temperatures, moisture content, drying time, air inlet temperature, and electric power consumption. Temperature was monitored using the mercury-in-bulb thermometers and a psychrometer. Moisture reduction was monitored after every pass through the dryer, i.e. after 36 or 48minutes, using a GANN 86 HYDROMETTE portable digital moisture meter. Samples were taken from the sacks used to collect the paddy from the bottom hopper for moisture content measurement. The moisture content was on wet basis.

Samples were also taken for milling and headrice recoveries to determine the quality of paddy rice dried using the dryer and compare with those using sun-drying. Sun-drying was carried out the same day with a polythene sheet laid on concrete pavement using the same variety used in the dryer.

First of all, the 1000 W electric heater was switched on and after about 7 minutes, the blower was started. The air inlet and outlet thermometers were then fixed, and the whole system was left to attain steady state, i.e. the thermometers giving steady initial readings. The paddy was loaded into the drying chamber at the top (Fig. 3.2). After taking the temperature readings, the roller-gear-motor system was started, and the rice was discharged from the bottom hopper, the rollers moving slowly, but steadily at about 1.0 rpm.

A psychrometer was utilized to take both the dry and wet-bulb temperatures of the outlet and the ambient air and the values recorded with those of inlet air and moisture content of the rice after every pass through the dryer.

3.3.4 Laboratory Milling of the dried Rice

Milling of paddy took place on 17th June, 2011 at the Rice processing Laboratory of the Ghana Irrigation Development Authority, Ashaiman-Tema, Greater Accra Region of Ghana. The milling process involved three stages: dehusking, polishing and grading. The moisture content of the samples was first taken using a grain moisture tester (Riceter J301). Samples of 250g each were weighed before being loaded into the hopper of the Satake Rice Dehusking Machine for dehusking to obtain brown rice.

The brown rice was again weighed and loaded into the Satake Rice polisher to get polished white rice. The weight of the white rice was also taken to be used to determine the head rice. The polisher was set to medium whiteness level. The time taken for polishing was about 1.5 minutes for each sample of the milled rice.

The Satake Test Rice Grader was used to separate the broken rice kernels from the whole rice after polishing. The rotating drum of the grader was set at an angle of 30° for the separation. Both the whole grain and broken rice were weighed and recorded.

3.3.5 Analysis of Milling Data

The main quality test for milled rice was the Head Rice yield (HRY) which is the mass by percentage of rough rice kernels that remain as head rice.

3.3.6 Field Data Collection (i.e. administering questionnaire to farmers) to determine the acceptability of the Dryer.

A questionnaire was designed for rice farmers in the rainfed rice growing areas of Jasikan, Hohoe and Kpando districts of Volta Region, and irrigated fields of Akuse-Asutsuare, Ashaiman of Greater Accra Region, and Nobewam and Besease in the Ashanti Region and Okyereko in the Central Region. See Appendix V for a sample of the questionnaire used.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1General Findings

Actual drying tests for the dryer were conducted in the Agric. Engineering Workshop on the KNUST campus. Table 4.1below summarizes the results of the technical evaluation.

Per batch, the highest amount of paddy rice dried was 250kg while the lowest was 176 kg.

Tests showed that paddy rice drying took from 4.8 to 5.6 h for an m.c. reduction from 26.6% to a minimum of 12.4% for the paddy consignments dried. The target m.c. was 12%.

4.2 Moisture Reduction

The drying rate ranged from 1.16% to 2.41%/h reduction of MC. It can be observed that moisture reduction was low at an average of 1.71%/h. This is to be expected, as the electric heater was insensitive to changes of heating as originally planned to give temperature readings of 40°, 50° and 60°C , but could give only a narrow range of up to 49°C. Thus the whole set-up can be taken as low-temperature, forced-air convection drying. It is possible to increase the rate of MC reduction; however, care was taken when attempting to increase the heat, as this can lead to grain stress (Schultz, 2004), which eventually leads to grain fissuring.

4.3 Thermodynamic Variations during the period of Drying

Temperature is one of the crucial parameters in paddy rice drying because it affects the rate of drying, viability of the seeds, and the quality of the milled rice (Ulep *et al*, *2005*). Figures 4.1(a) to 4.4(d) presents the variations in temperature, relative humidity, moisture content, humidity ratio and enthalpy during the drying process. It can be seen that the peak temperatures were observed before and after midday.

Table 4.1: SUMMARY OF RESULTS

Loading Date	**Sundrying** 1st April	**Consign1** 2nd April	**Consign2** 3rd May	**Consign3** 5th May	**Consign4** 2nd June
Capacity	30 kg	176 kg	250kg	250kg	250kg
Initial Mc	22.70%	19.70%	20.90%	21.70%	26.60%
Final Mc	11.80%	13.50%	13.30%	12.40%	13.10%
Drying Time (HOURS)	5	5.3	5.7	4.8	5.6
Drying Rate (Δmc%/Hour)	2.18	1.16	1.33	1.94	2.41
LABORATORY MILLING DATA					
MC(at milling)	13.60%	13.70%	15.10%	14.40%	14.50%
Paddy mass	250g	250g	250g	250g	250g
Brown rice mass	185.9g	187.7g	181.9g	187.0g	187.5g
White rice mass	155.9g	158.6g	155.3g	158.5g	157.8g
Head rice	107.5g	117.9g	126.2g	122.1g	113.8g
% Head rice yield HRY	42.80%	46.80%	50.40%	48.80%	45.20%

SUMMARY OF THERMODYNAMIC PROPERTIES					
					MEAN VALUES
H. U. F.	54.70%	51.90%	87.10%	80.50%	**68.60%**
C. O. P.	45.30%	48.10%	12.90%	19.40%	**31.40%**
E. H. E.	39.80%	36.40%	57.80%	62.70%	**49.20%**

Also, the difference in temperature between the plenum chamber and grain mass was about 4°C. Drying air temperature was 3°C higher than the ambient air during bright, sunny weather, on the average.

4.3.1 Ambient, Inlet, and Outlet air Temperature, and Moisture content variations with Time

In Figs. 4.1 (a) to (d), while the inlet temperature remains almost constant, the outlet dropped sharply from the steady state at the beginning when there was no rice in the drying chamber. As soon as the rice was poured the outlet air temperature dropped to attain that of the rice.

In all cases the temperatures increase as the day wears on to midday. The moisture content MC is seen to decrease steadily to the required value. Also the outlet air temperature is lower than the inlet, which confirmed the existence of temperature driving force for heat flow.

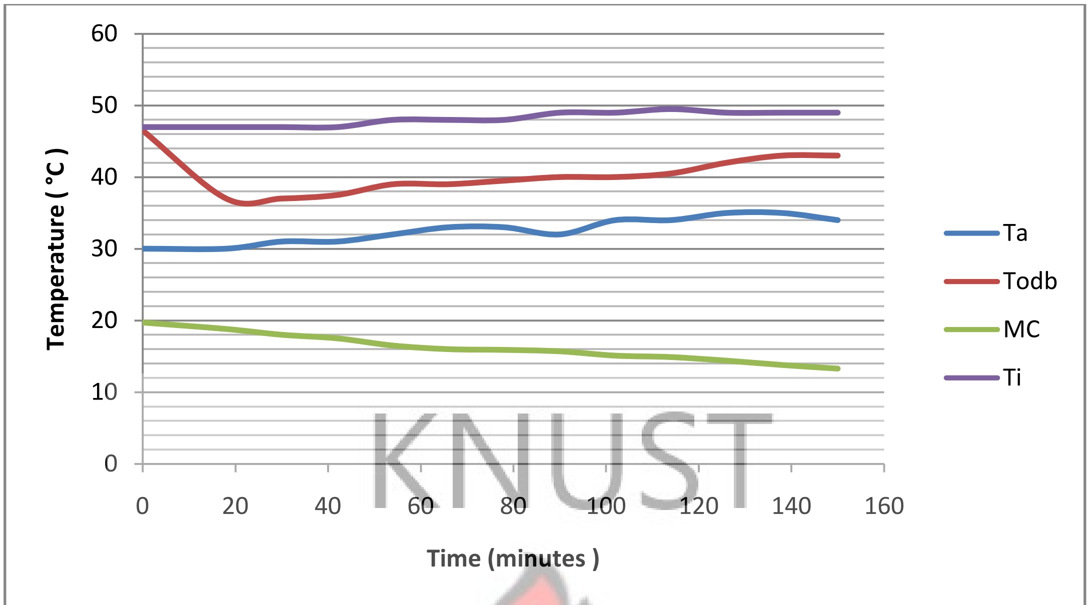

Fig. 4.1 (a) Temperature variation of ambient (T_a), outlet (T_{odb}), inlet (T_i) and MC; Consignment 1.

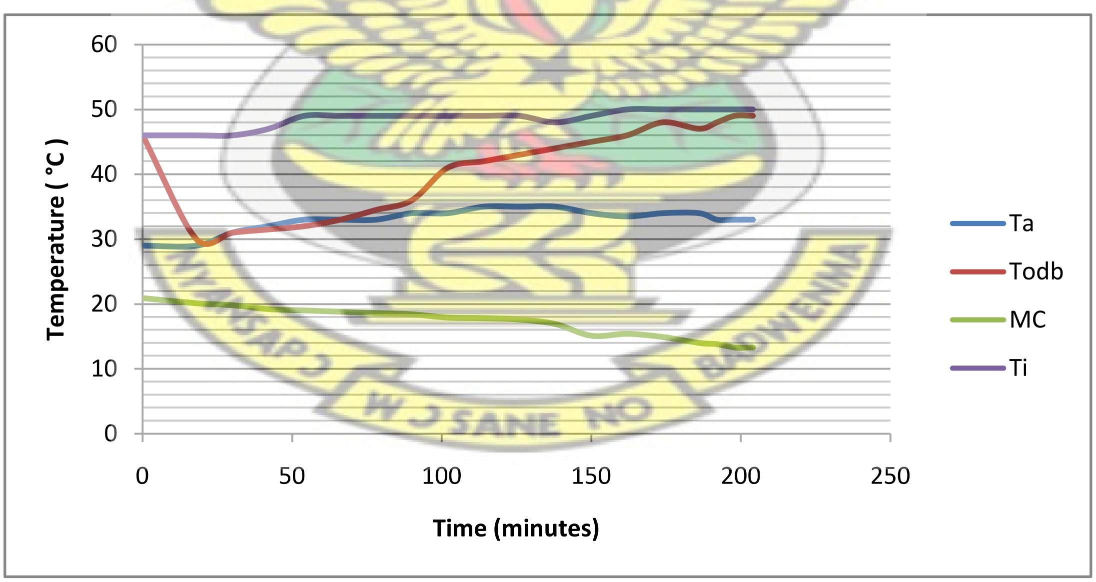

Fig. 4.1 (b) Temperature variation of ambient (T_a), outlet(T_{odb}), inlet(T_i) and MC; Consignment 2.

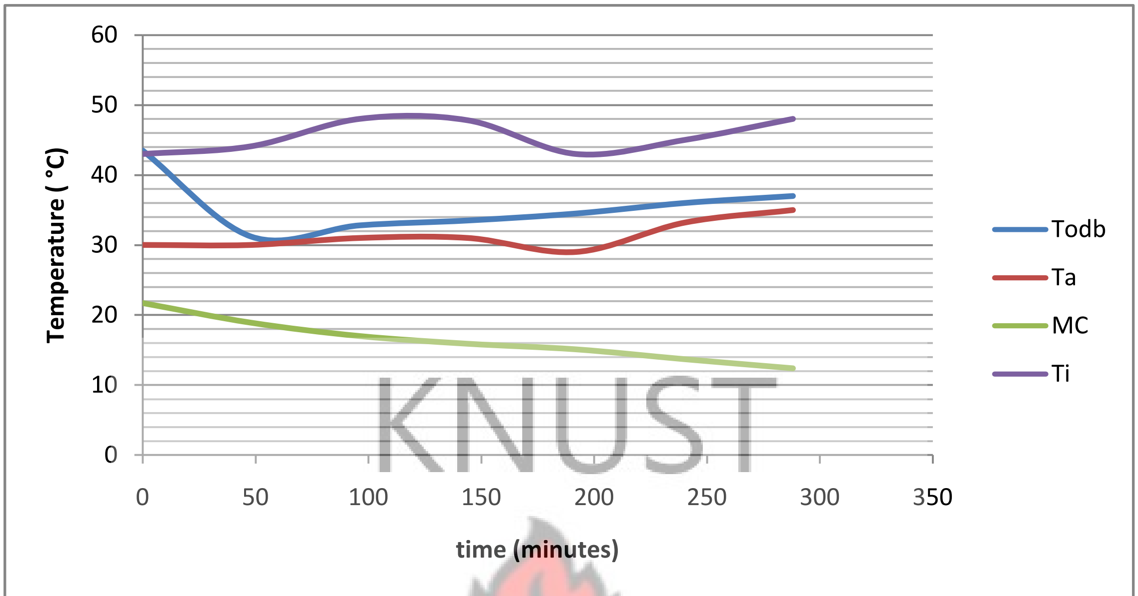

Fig. 4.1(c) Temperature variation of ambient(T_a), outlet(T_{odb}), inlet(T_i) and MC; Consignment 3.

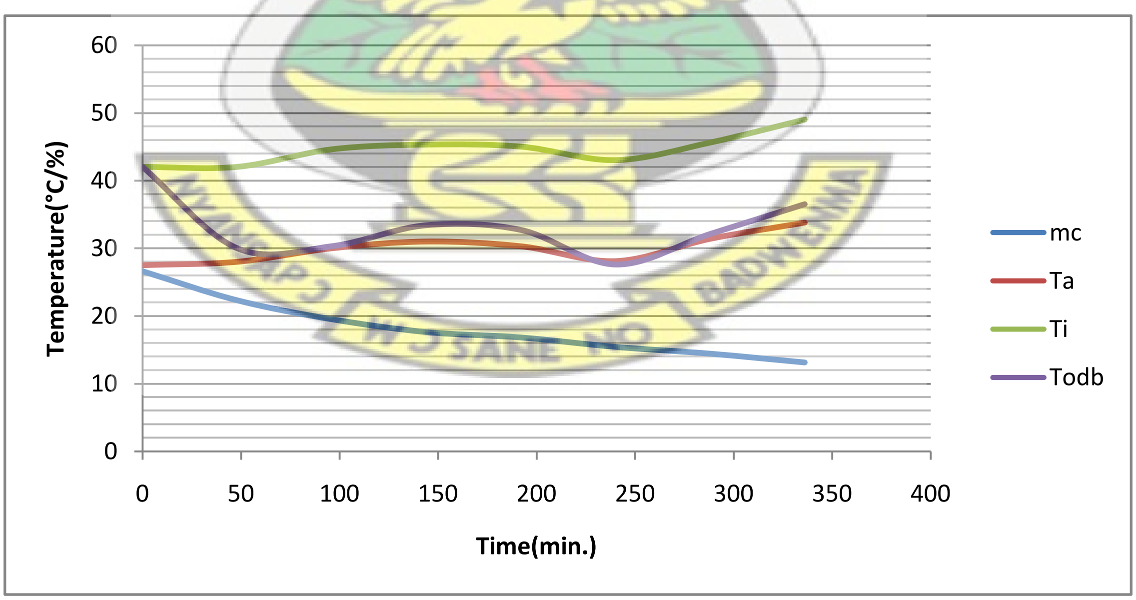

Fig. 4.1 (d) Temperature variation of ambient(T_a), outlet(T_{odb}), inlet(T_i) and MC; Consignment 4.

4.3.2 Relative Humidity of Ambient and Outlet air, and Moisture Content variations

Relative humidity graphs Figs.4.2 (a) to (d) show that at the beginning of attaining steady thermometer readings, the relative humidity of the air in the drying chamber was very low, but rises sharply as soon as the rice is poured into the drying chamber**.**

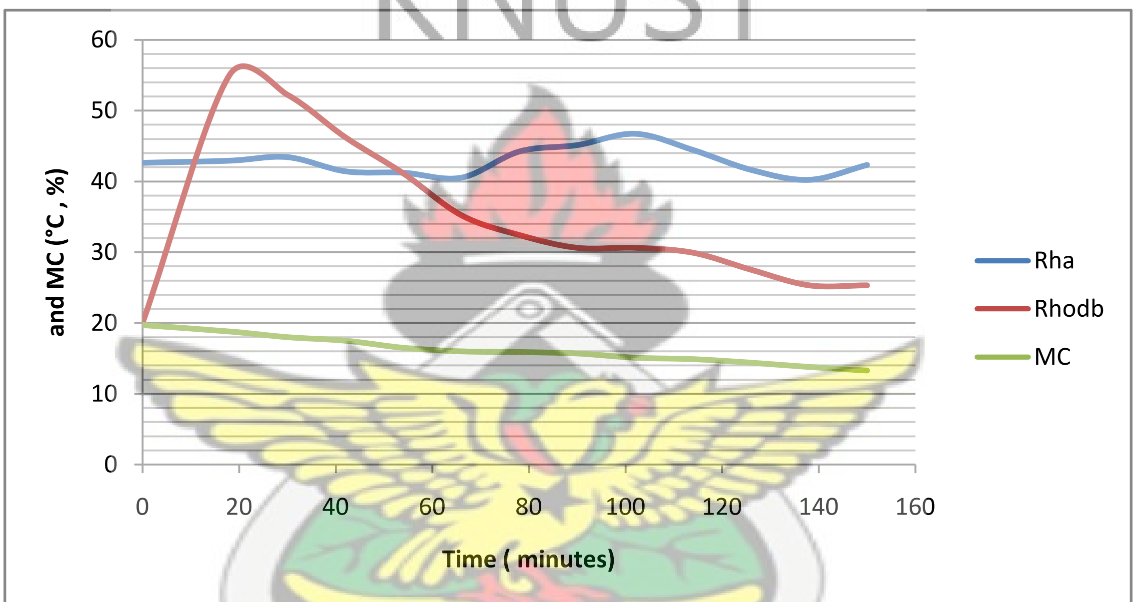

Fig.4.2(a) **Relative Humidity of ambient(Rh_a), outlet (Rh_{odb}) of air, and MC variations for consignment 1**

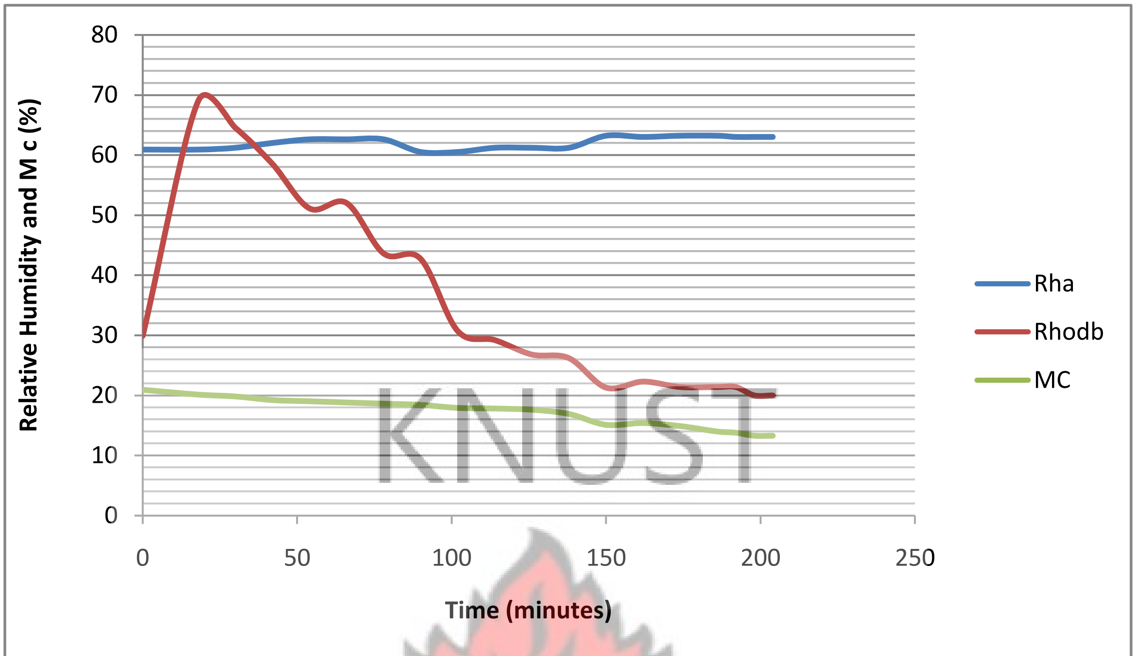

***Fig. 4.2** (b)* **Relative Humidity of ambient(Rh$_a$), outlet(Rh$_{odb}$) of air, and MC, for Consignment 2.**

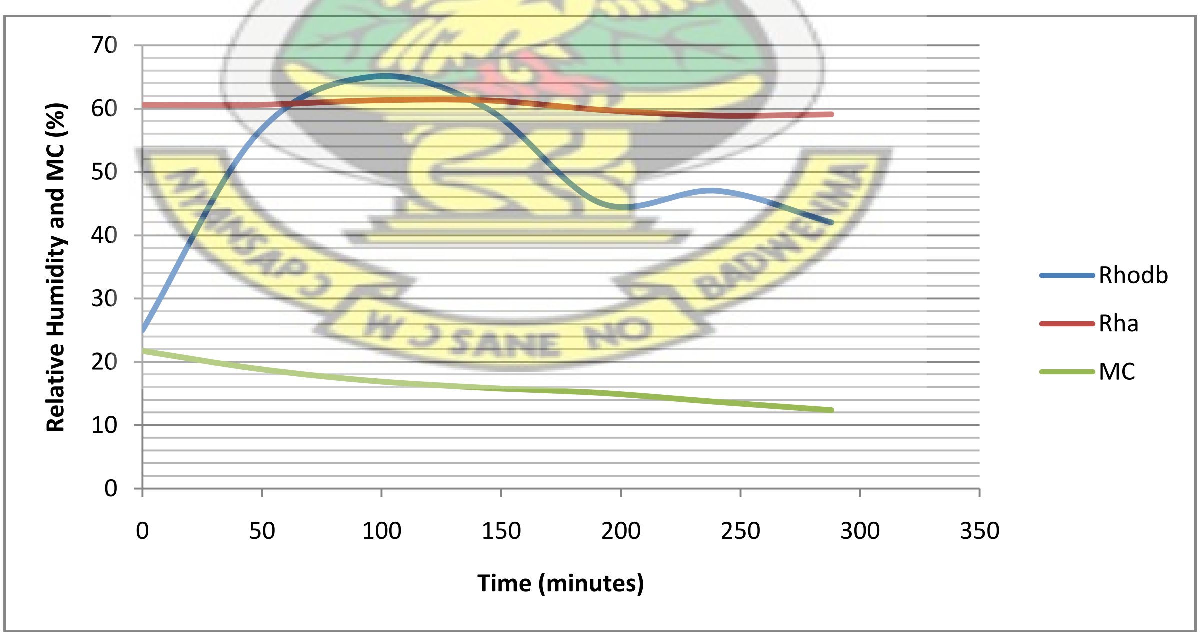

Fig. 4.2 (c)relative Humidity variations of ambient(Rh$_a$), outlet(Rh$_{odb}$) of air and MC for Consignment 3

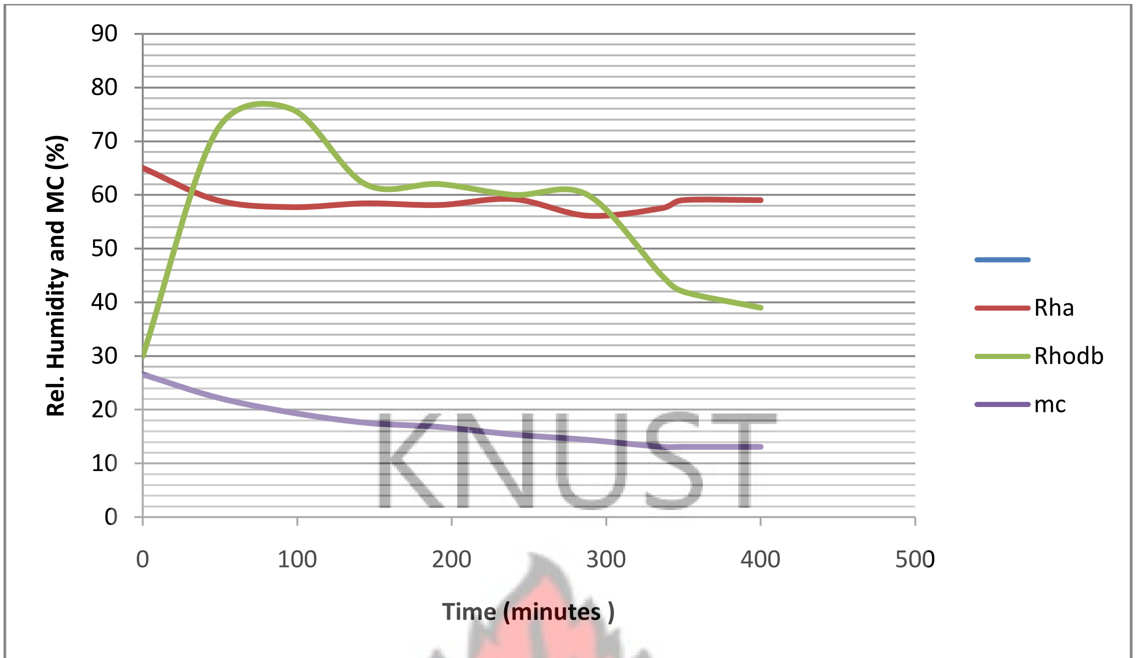

Fig. 4.2 (d) Relative Humidity variation of ambient(Rh_a), outlet(Rh_{odb}) and MC for Consignment 4

4.3.3 Humidity Ratio variation of Ambient and Outlet air

As indicated on Figs. 4.3 (a) to (d), the humidity ratio of the outlet air for the first few minutes of drying increase and steadily decreased afterwards. The sharp increase was due to faster removal of surface moisture of the paddy. Towards the end of drying, the outlet moisture tended to be in equilibrium with the ambient, confirming completion of drying. Paddy rice Consignment 3 did not show any equilibrium in this case.

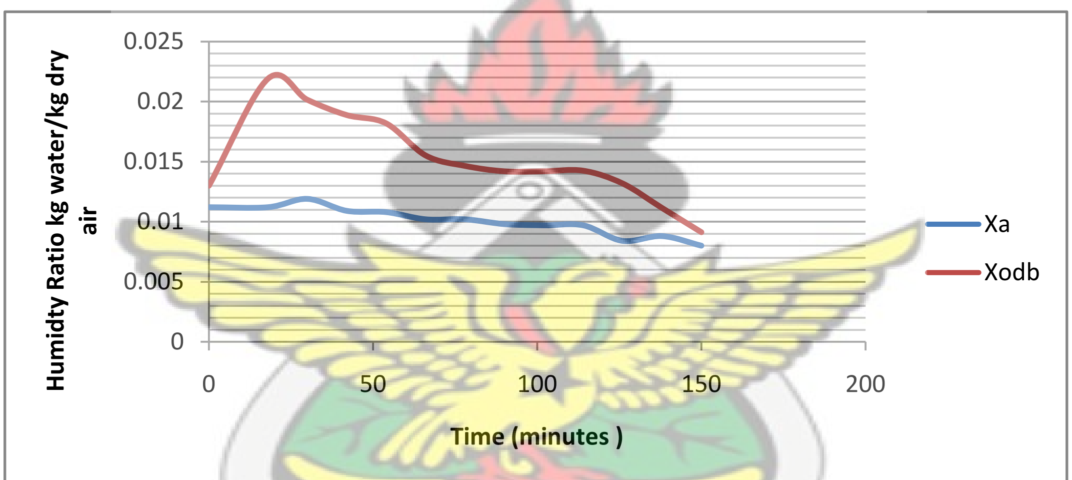

Fig.4.3 (a) Humidity Ratio of ambient (X_a), and outlet (X_{odb}) air variations during drying for Consignment 1.

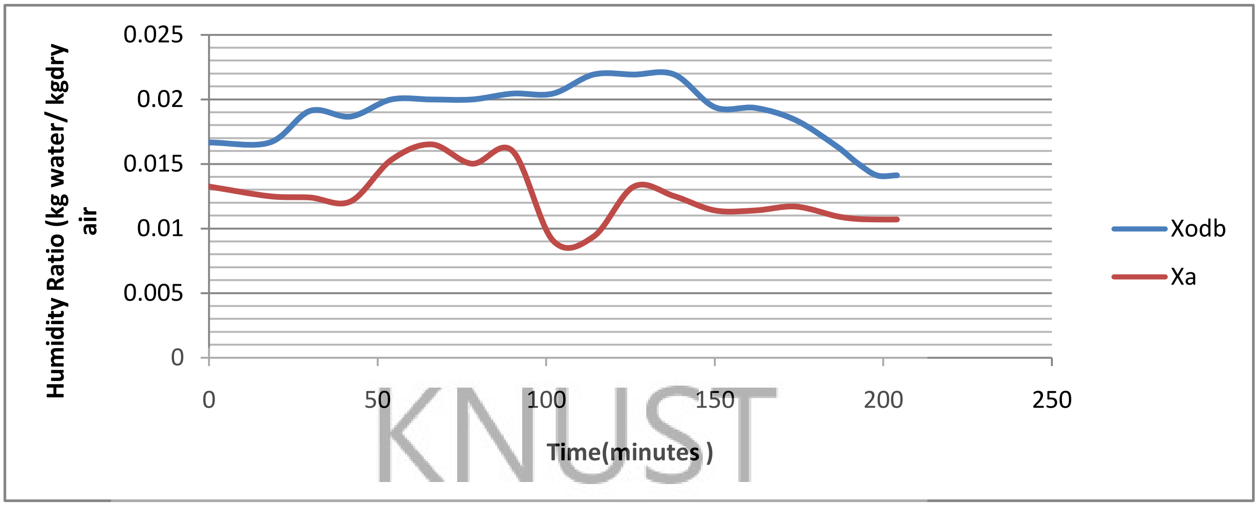

Fig.4.3(b) humidity Ratio of ambient(X_a) and outlet(X_{odb}) of air during drying for Consignment 2

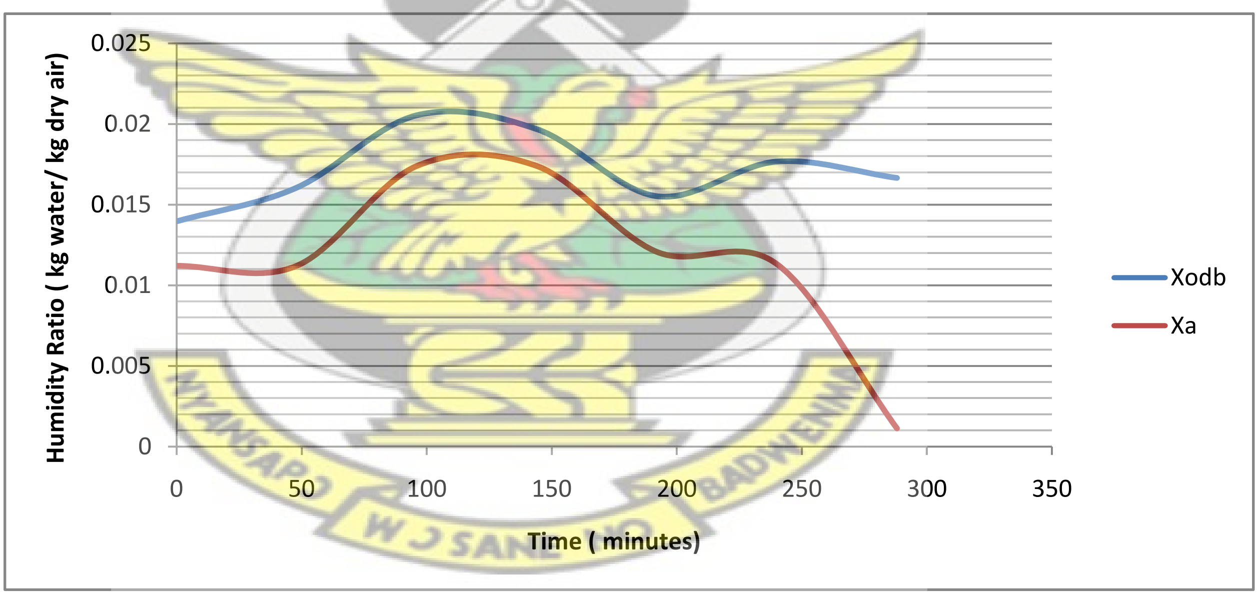

Fig.4.3(c) humidity Ratio of ambient(X_a) and outlet (X_{odb}) of air during drying for Consignment 3.

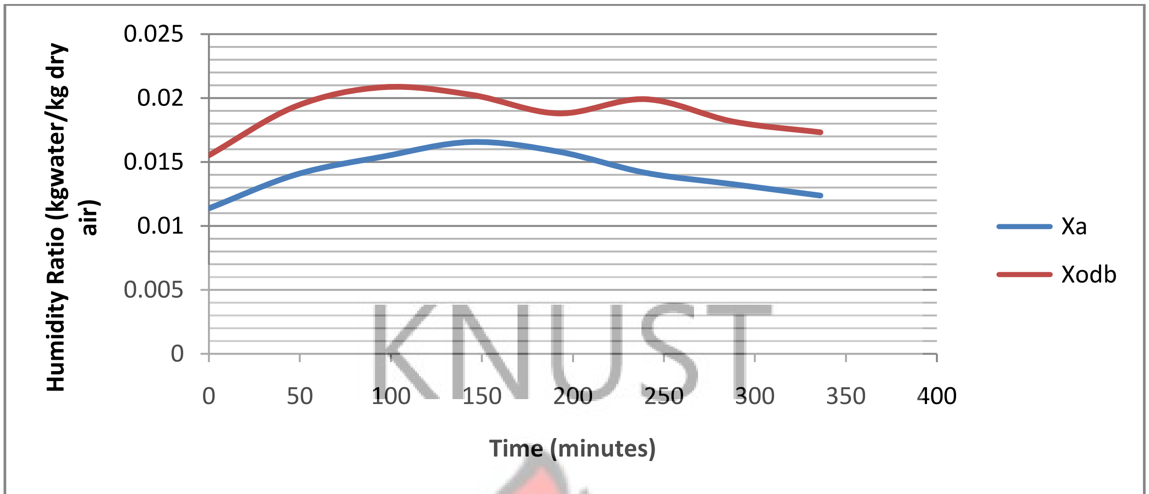

Fig.4.3(d) Humidity Ratio of ambient (X_a) and outlet (X_{odb}) of air during drying for Consignment 4

4.3.4 Enthalpy variations of Ambient and Outlet air

The enthalpy condition of the dryer was similar to that of humidity ratio, figs.4.4 (a) to (d). The sharp increase in enthalpy was due to faster removal of surface moisture of the paddy. Towards the end of drying, the outlet moisture tended to be in equilibrium with the ambient, confirming completion of drying:

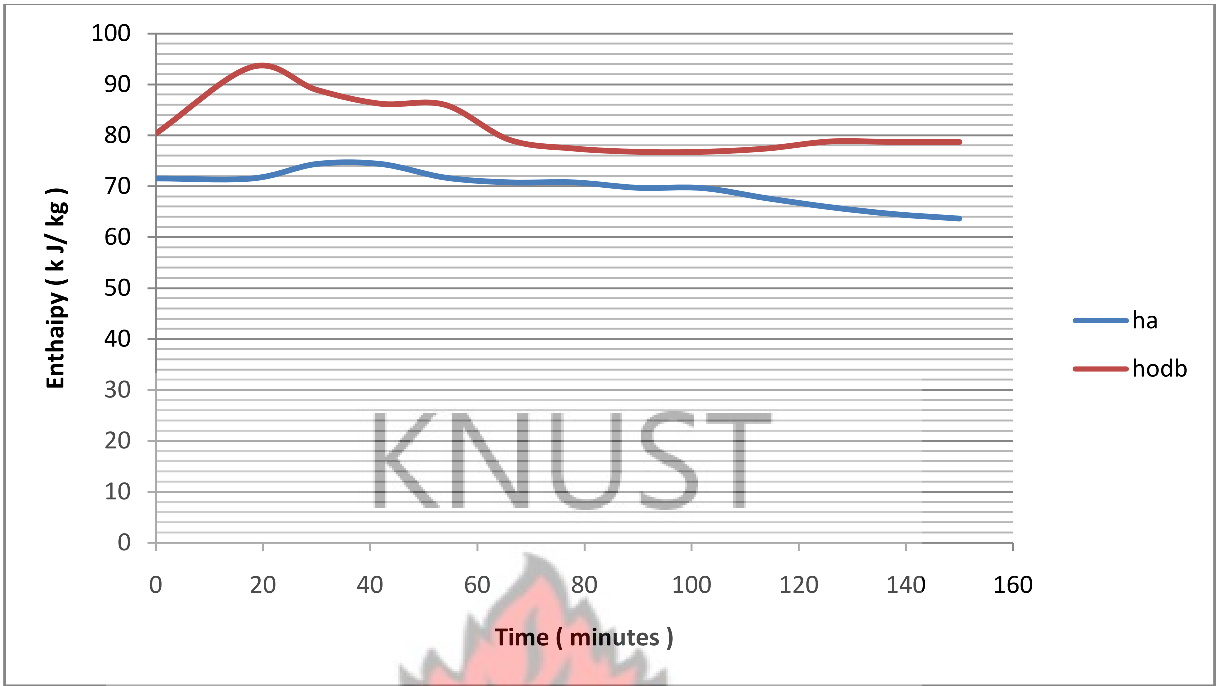

Fig.4.4(a) Enthalpy variation of ambient(h_a) and outlet(h_{odb}) air during drying for Consignment 1.

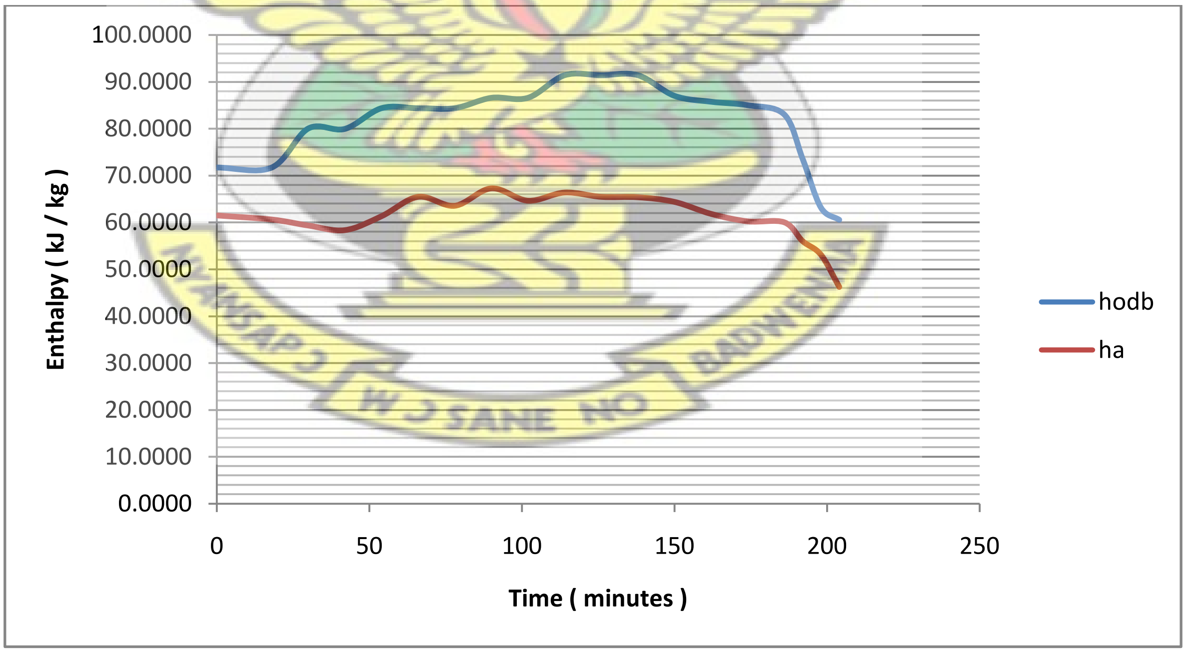

Fig.4.4(b) Enthalpy variation of ambient(h_a) and outlet(h_{odb}) air during drying for Consignment 2.

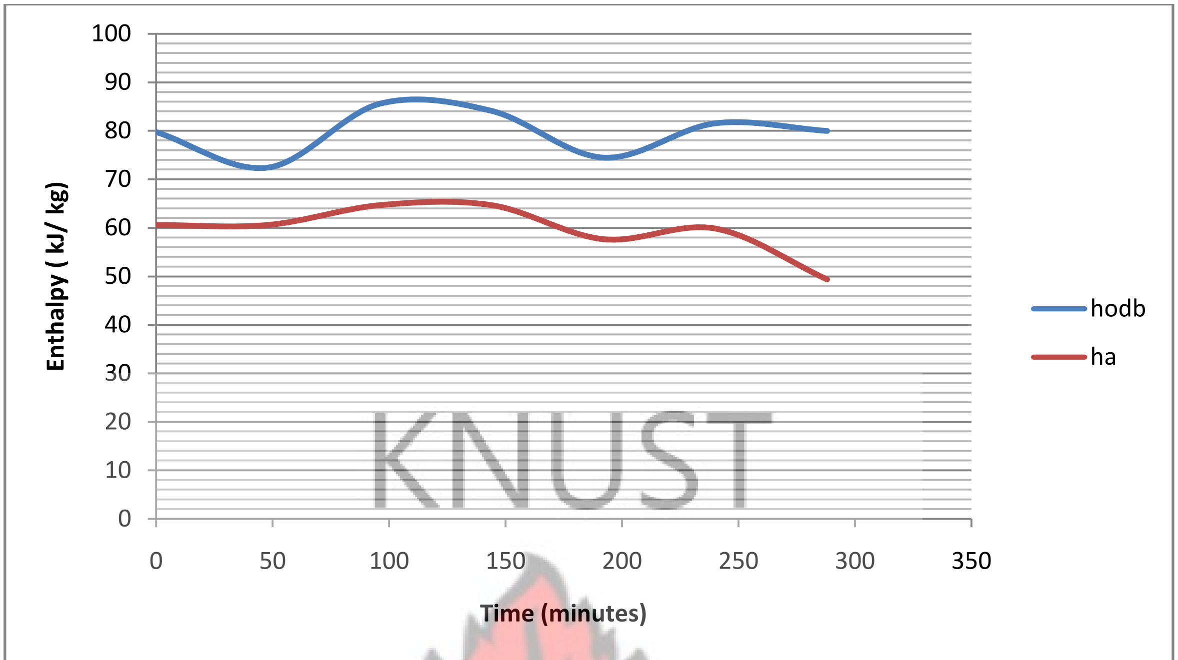

Fig.4.4(c) Enthalpy variation of ambient(h_a) and outlet(h_{odb}) of air during drying for

Consignment 3.

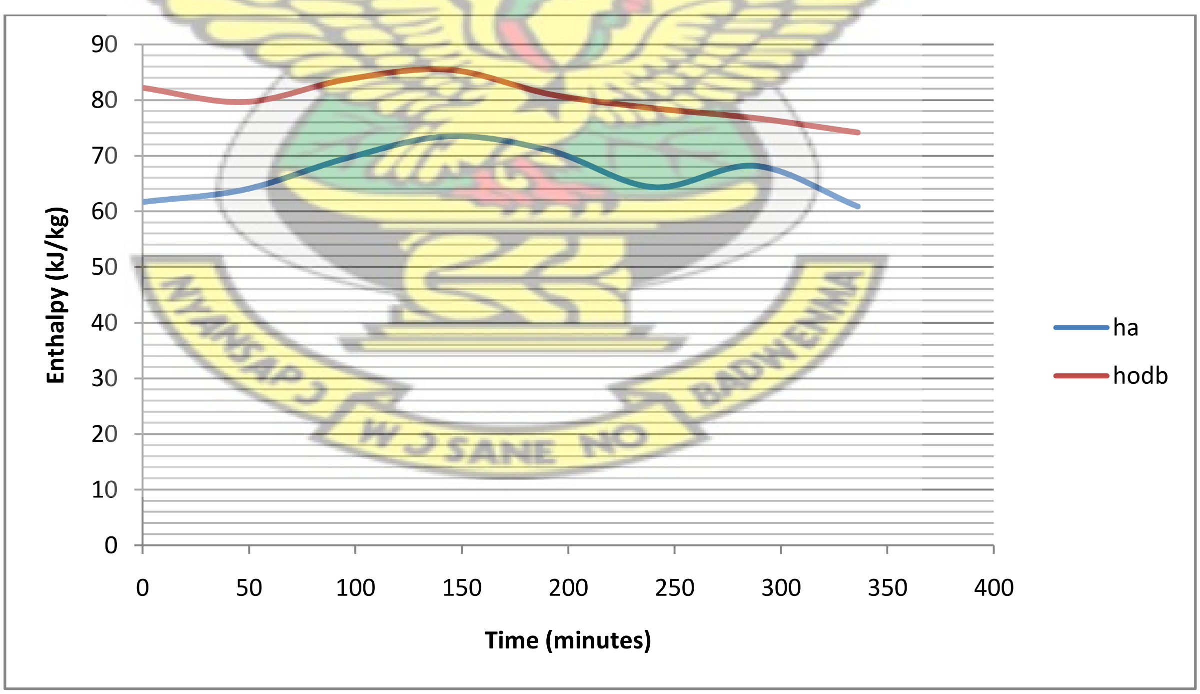

Fig.4.4(d) Enthalpy variations of ambient(h_a) and outlet(h_{odb}) air during drying for Consignment 4.

4.3.5 Analysis of Milling Data

Milling and headrice recovery or the Head Rice Yield (HRY) are important criteria in assessing the quality of the paddy rice, which is greatly influenced by drying. Headrice recovery or HRY is the percent headrice ratio of the weight of grains that do not break in the process of milling and with the size of ¾ or more of the whole grain, to the total weight of milled rice, expressed in percent (Ulep *et al.*, 2005).

The average milling and headrice recovery rates are shown in Figs.4.5 (a) to (d). The mechanically dried samples had higher milling and headrice recovery rates than the sun-dried samples. This indicates that there was more grain damage in the latter sample as can be seen from summary of results shown Table (4.1).

The drying rates, Δmc%/h for mechanical drying are 1.16, 1.33, 1.94 and 2.41, and that for the sundrying is 2.18%. This agrees with the standard of 1-3% moisture reduction per pass using mechanical dryers. Though the sundrying rate is within the standard interval, it was very drastic in that the moisture was reduced from 22.7% to 11.8% within 5 hours. Thus sundrying had the lowest headrice yield of 42.8%. The average HRY is 48.0% compared with 58-61% by Sutherland and Ghaly(1992), and 55% by commercial millers in the Philippines (IRRI,2009). Average milling recovery was 63% compared to 69-70% maximum, 65% by commercial millers, (Sutherland and Ghaly, 1992), and 58% (IRRI, 2009).

The average dryer efficiency attained was 49.2% compared to that of 51% (FAO, 2002). The mean values of heat utilization factor (HUF) and coefficient of performance (COP) were respectively 68.6% and 31.4%.

4.3.6 Field Data Analysis

The summary of the responses to the questionnaire administered to farmers to determine the acceptability of the dryer, see Table 4.2. The field work concentrated on the southern part of Ghana with rainfed and irrigation rice production. It is clear from the table that farmers have very small fields for growing rice, from 0.4 to 2.0 and over hectares. The yields range from 1.2 to 3.0 tonnes per hectare. This variation in yield per acre is due to the cultural practices applied, such as good timing, chemical application (weedicides, insecticides, and fertilizers), weed control in the growing rice and harvesting practices. It is also seen that the number of crops per year is 2 and nobody uses a dryer to dry the fresh paddy produced. Almost all expressed interest in the dryer, a few can afford to one at GHc 5,000.00, and majority are ready to collectively own one. Again

almost all the respondents are to grow a particular species of rice specified by rice dealers, and some of them cultivate other grains such as maize, soya beans, beans and groundnuts, all of which can be dried with the mechanical dryer.

From design, development, evaluation and to field data collection, it can be said that the dryer is better than sundrying in terms of capacity, convenience of operation, and quality of dried product (in this case paddy rice).

Table 4.2: SUMMARY OF RESPONSES OF FARMERS TO QUESTIONAIRE
(Questionnaire Adminisration)

FIELDS: Rainfed rice growing villages of Jasikan, Hohoe and Kpando distrcts of Volta Region, Irrigated fields of Akuse-Asutsuare, Ashaiman, Nobewam , Besease. Okyereko **No. of Respondents=71**

Questionnaire item	Responses	Frequency
Field size: (2.5 acres= 1hectare)	0.4 hectare	18
	0.8 hectare	17
	1.2 hectares	20
	1.6 hectares	7
	2 or> 2 hectares	9
Quantity produced per 0.4 hectare (1 bag = 84 kg)	14 bags	4
	15 bags	5
	20 bags	23
	25 bags	20
	30 bags	11
	35 bags	8
	40 bags	0
Number of crops per year	1 crop	41
	2 crops	30
	3 crops	0
Current use of dryer	No use	0
Need of dryer	Need expressed	69
Affordability of dryer (@ ≈ GH¢ 5,000)		24
Cooperative ownership of dryer		43
Dryer to enhance production		58
Availability of irrigation		41
Immediate drying(8 to 24 hours after harvesting)		0
Readiness to grow a particular species wanted by market or dealers		68
Any other grain grown that can utilize dryer:	maize	23
	soya beans	3
	beans	15
	groundnuts	2
	None of the above	28

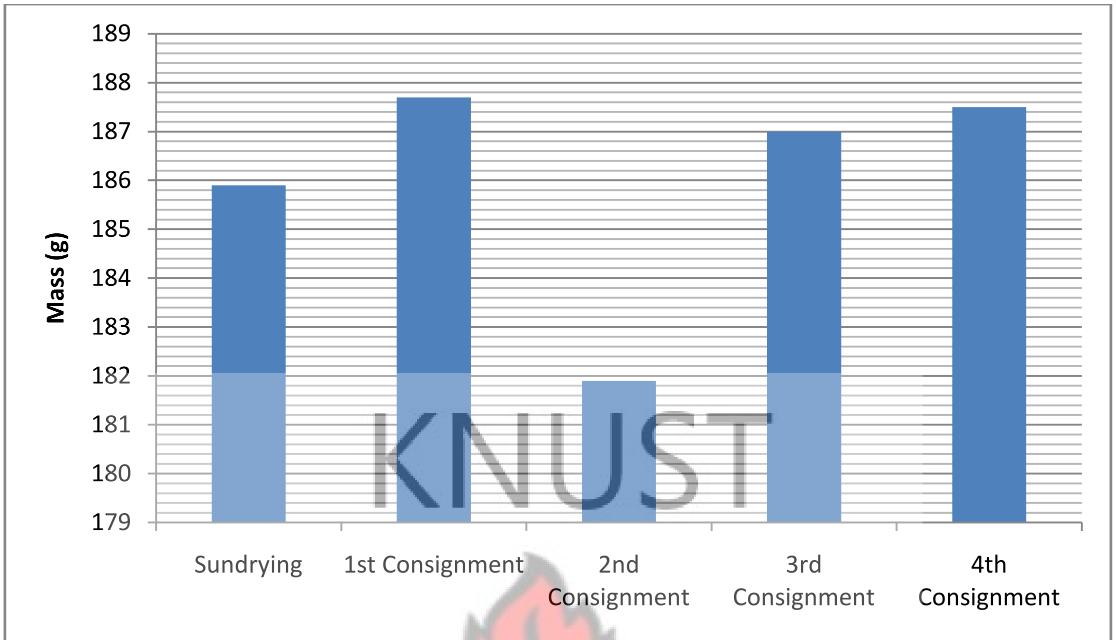

Fig. 4.5 (a) Brown Rice yield (g)

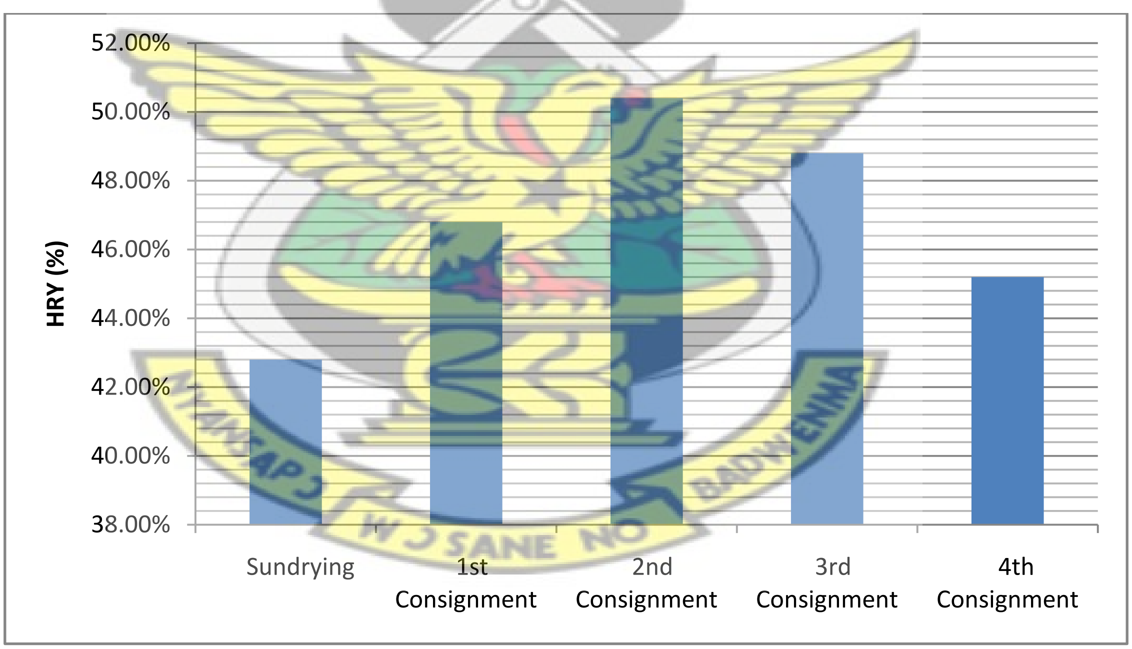

Fig. 4.5 (b) Headrice yield (%)

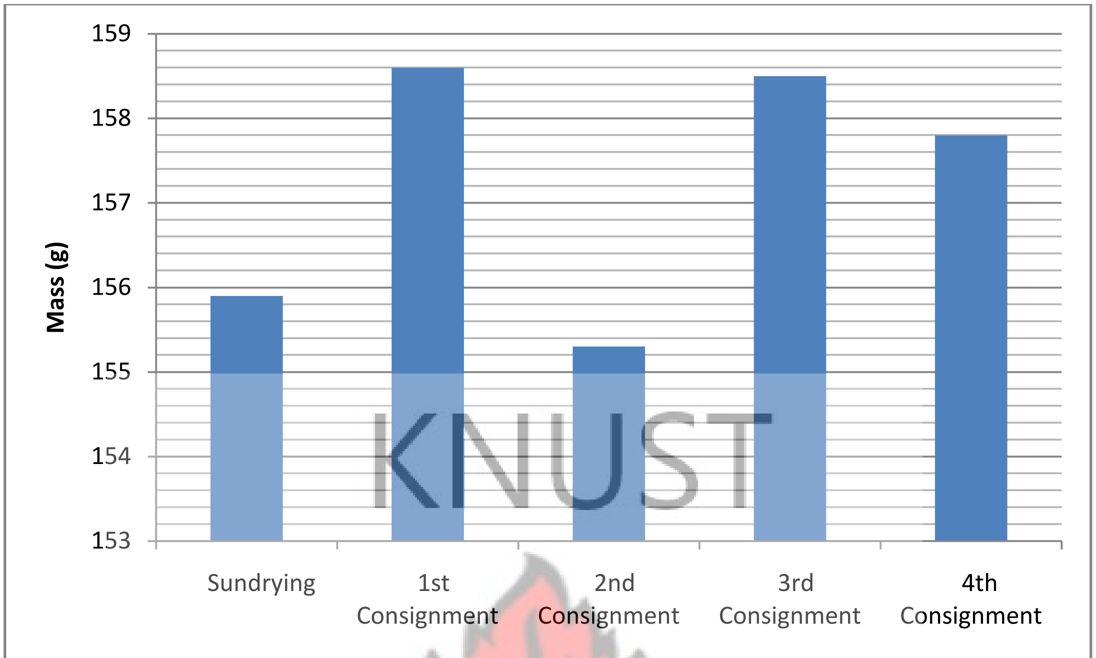

Fig. 4.5 (c) White rice yield by mass (g)

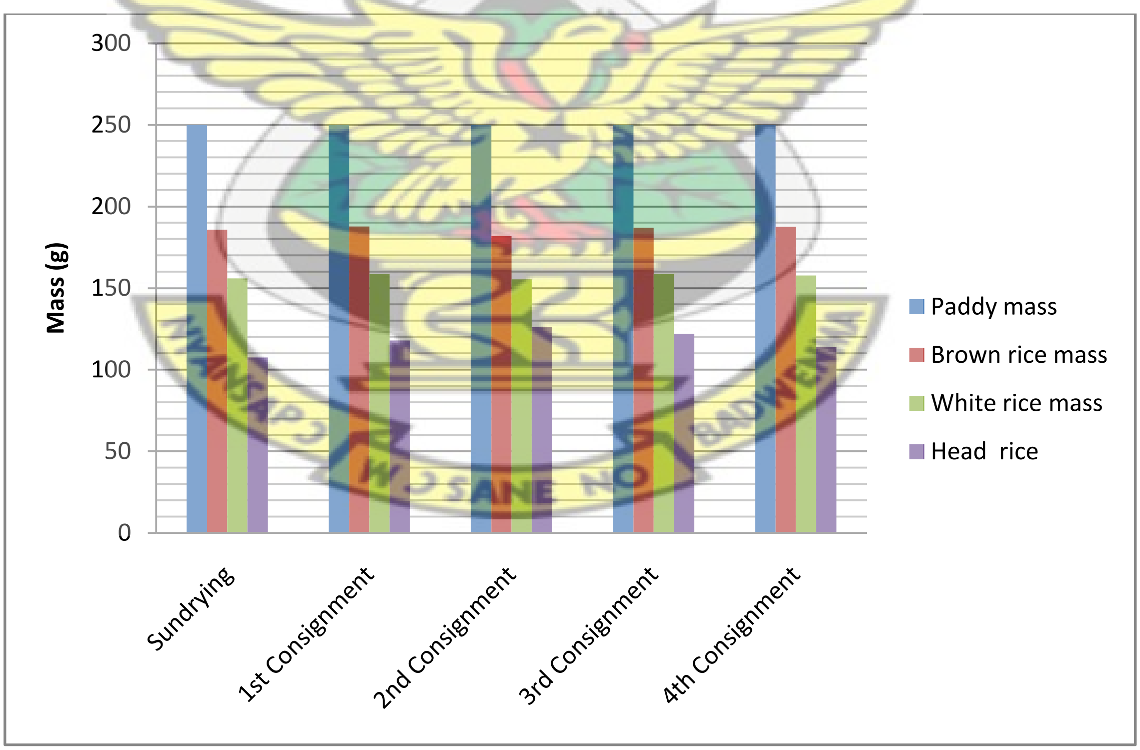

Fig.4.5 (d) Comparison of all milling yields

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Although there are many available dryers, the continuous-flow mixing grain dryer is built locally, using the available materials. It is recommended as it has proven to be the better alternative for the drying of paddy rice in the sun. Various capacities of the dryer can be built to suit the small farm holding units of the peasant farmers in the country as well as large capacities for large scale farmers.

Questionnaire put to farmers in the Jasikan, Hohoe and Kpando Districts of Volta Region, who practised rainfed rice farming, and the irrigation-assisted areas of Nobewam and Besease near Kumasi in the Ashanti Region of Ghana show that farmers are ready to form co-operatives to be able to buy this dryer when it becomes available.

The advantageous features of the dryer include:

(a) simple design, as it uses only locally available materials. Though this prototype was built using metal wood can also be used to further reduce cost.

(b) affordable cost, not as expensive as the imported variants.

(c) appropriate capacity for small individual farmers, from 250 kg upwards.

(d) portable and convenient to transport,

(e) No foundation is required for its installation.

(f) Versatile, as it can be used to dry not only rice but other grains, and

(g) easy operation and installation.

(h) superior headrice yield and quality. When the rest of the rice was sent for commercial milling, after taking the samples for analysis, the milling yield was much superior to the sundrying quality. A woman trader actually recommended this dryer dried rice to be sold out quickly; otherwise their low quality would get the market.

(i) Vegetable waste such as rice husks, corn cobs, wood and charcoal from cultivated woodlots can be burnt to provide the necessary heat for drying, thereby further reducing operation costs of the dryer.

During the actual process of drying, farmers may become impatient and choose to speed up the drying of their paddy rice. It is emphasized that caution should be taken in such a case, as drying the grains too quickly with heated air can lead to grain damage.

5.2 RECOMMENDATIONS

Aside from promotion through any of the mass media (print, radio, TV), access to funds is an important consideration for the eventual adoption of the technology. For that matter, there are at least two other options that can be taken:

(a) single ownership and

(b) group ownership.

Individual ownership of the dryer is for farmers who can easily raise the necessary funds individually by themselves, or can have access to funds without much difficulty; group ownership is for the farmers who need financial assistance. Government financial assistance is another option.

On the matter of further developing the technology itself, it is also important to reduce further the cost by:

(i) designing and developing a bucket or pneumatic conveyor to accompany the dryer for easy loading and offloading.

(ii) evaluate the dryer with other grains like maize, beans, soya, sorghum, millet and seeds like coffee, peppers, and even for cocoa beans when specially designed.

This is one of the few projects in which a prototype was developed straightaway, and found immediate application. Thus it is further suggested that the KNUST either make funds available to further develop the prototype and install it at Nobewam as a demonstration type which will be another innovation by KNUST and for that, money can be earned from it.

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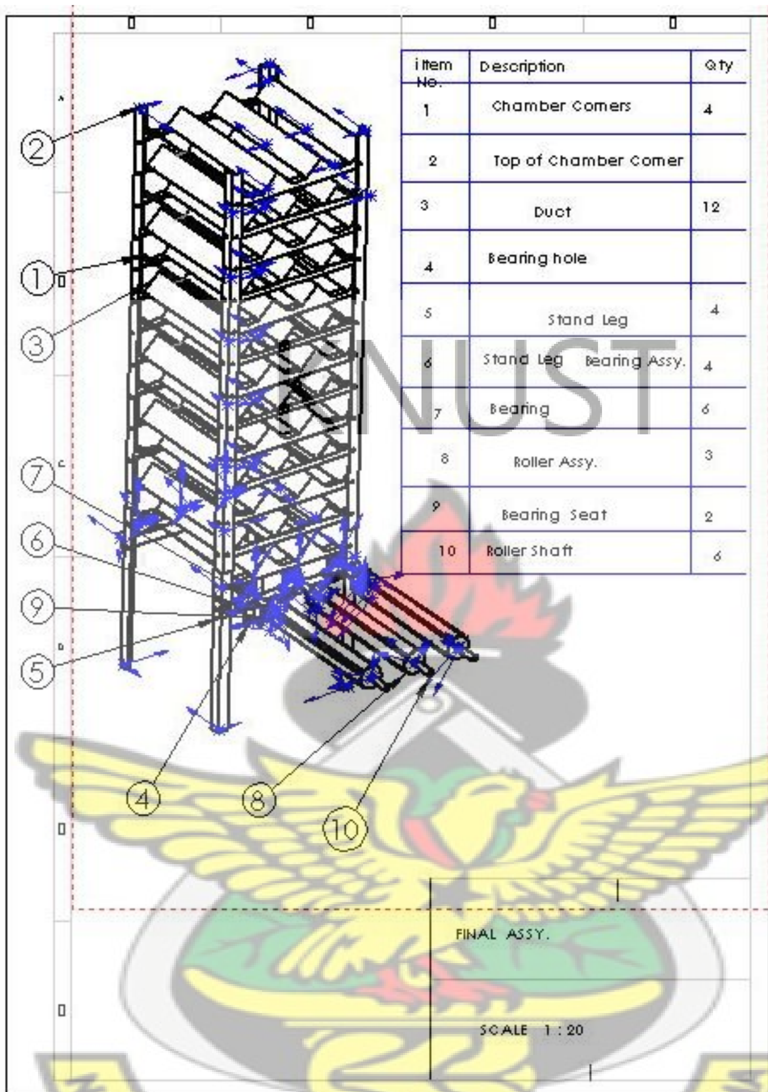
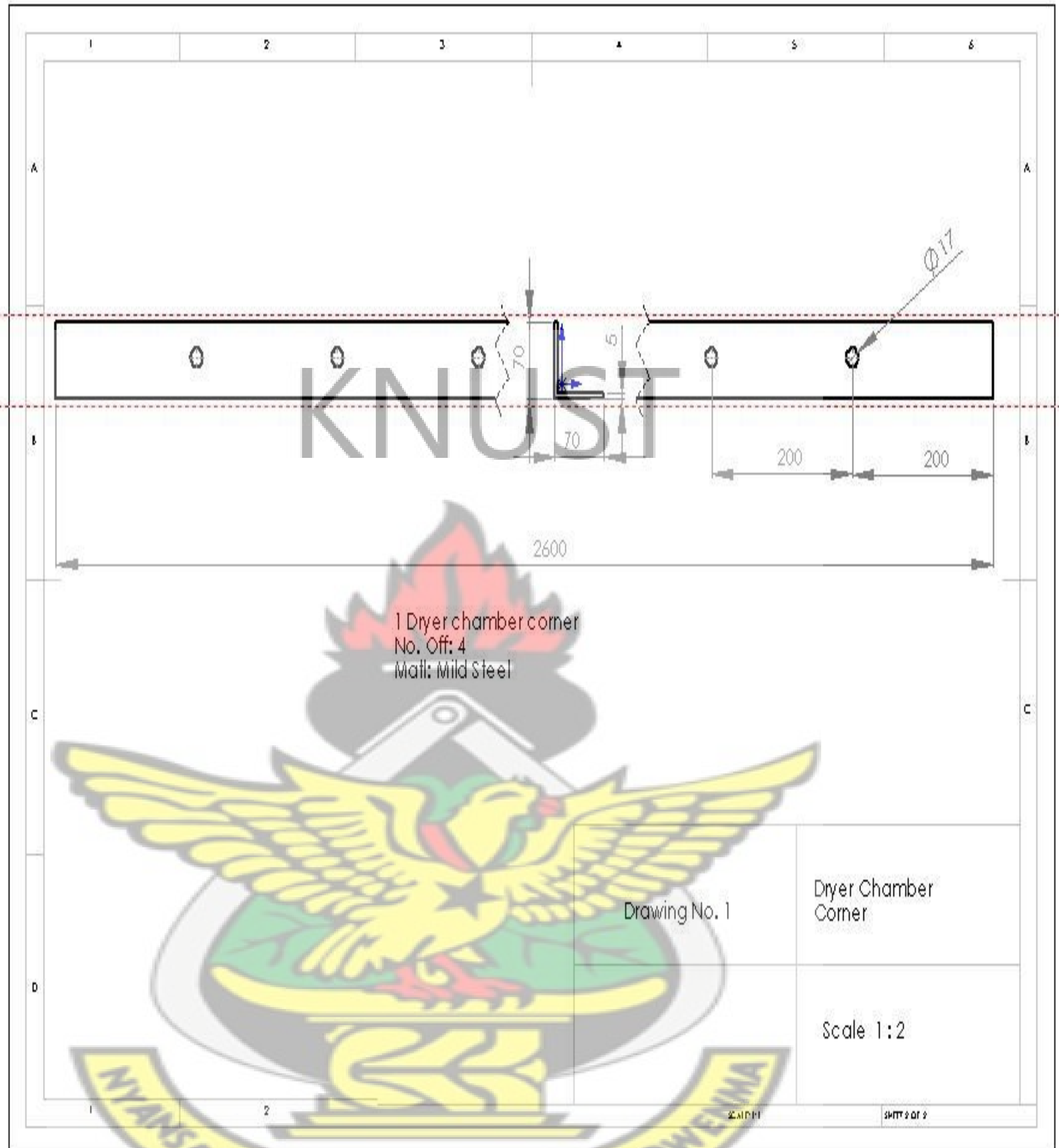
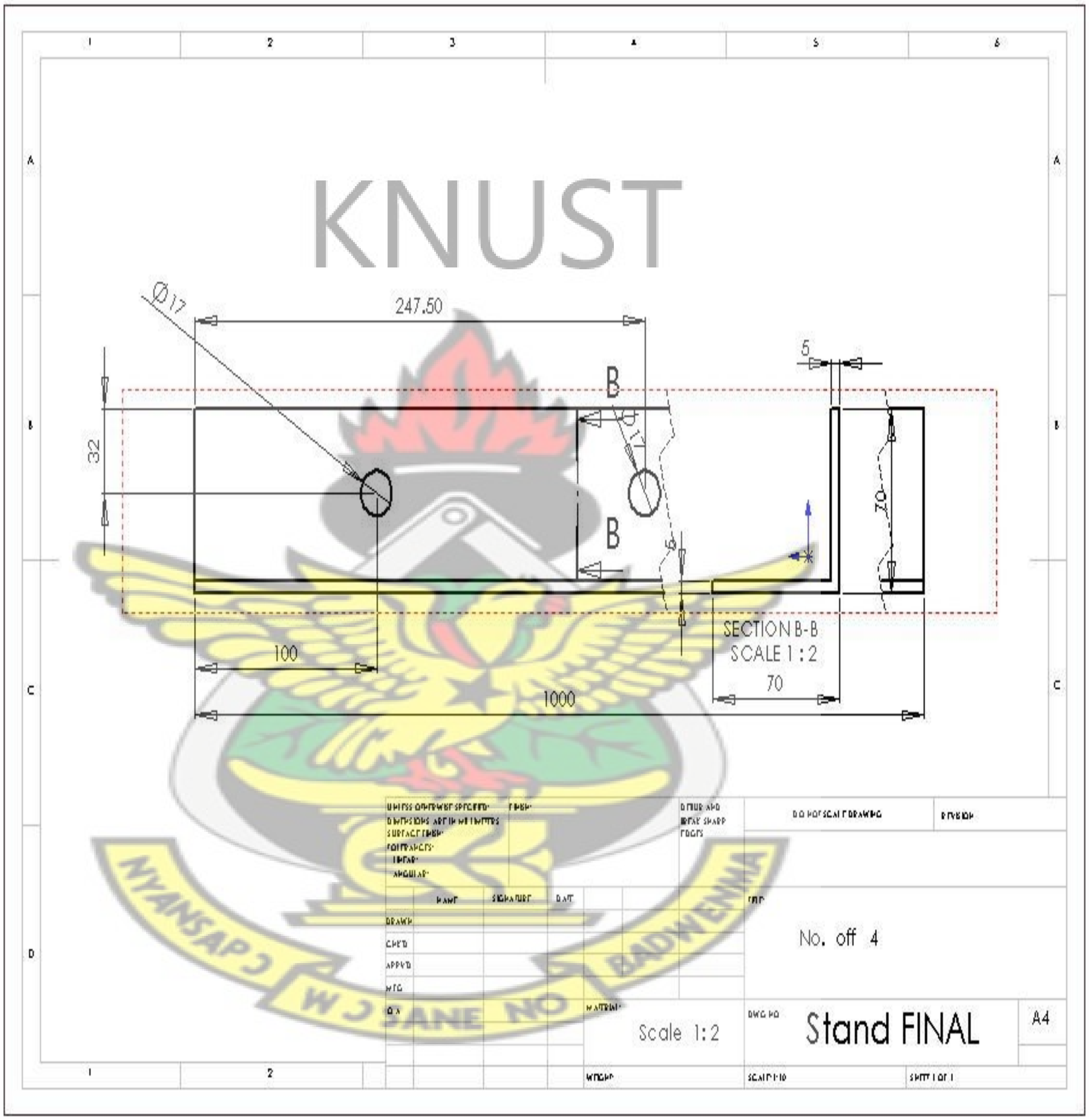
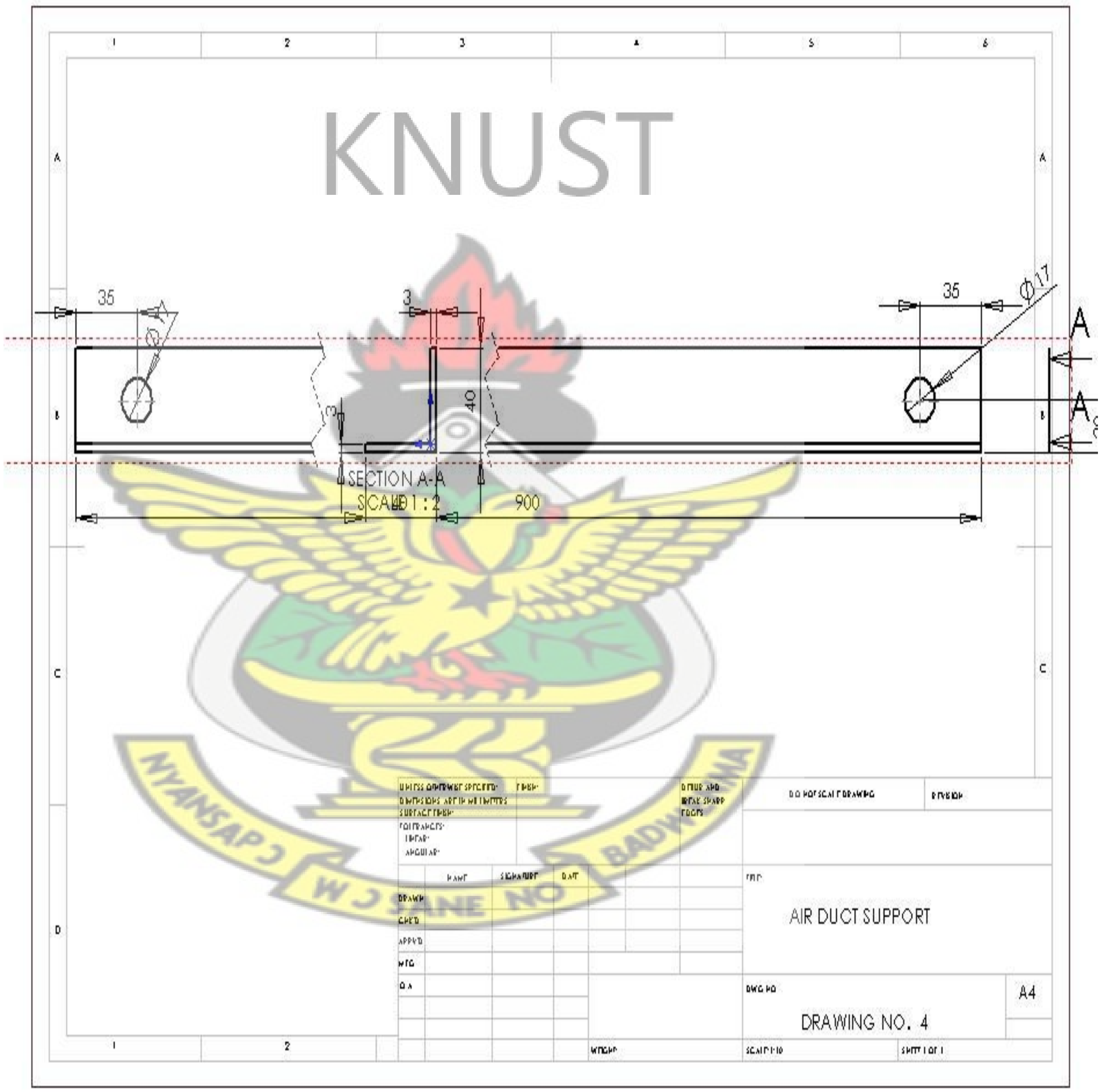
APPENDIX I Design Drawings

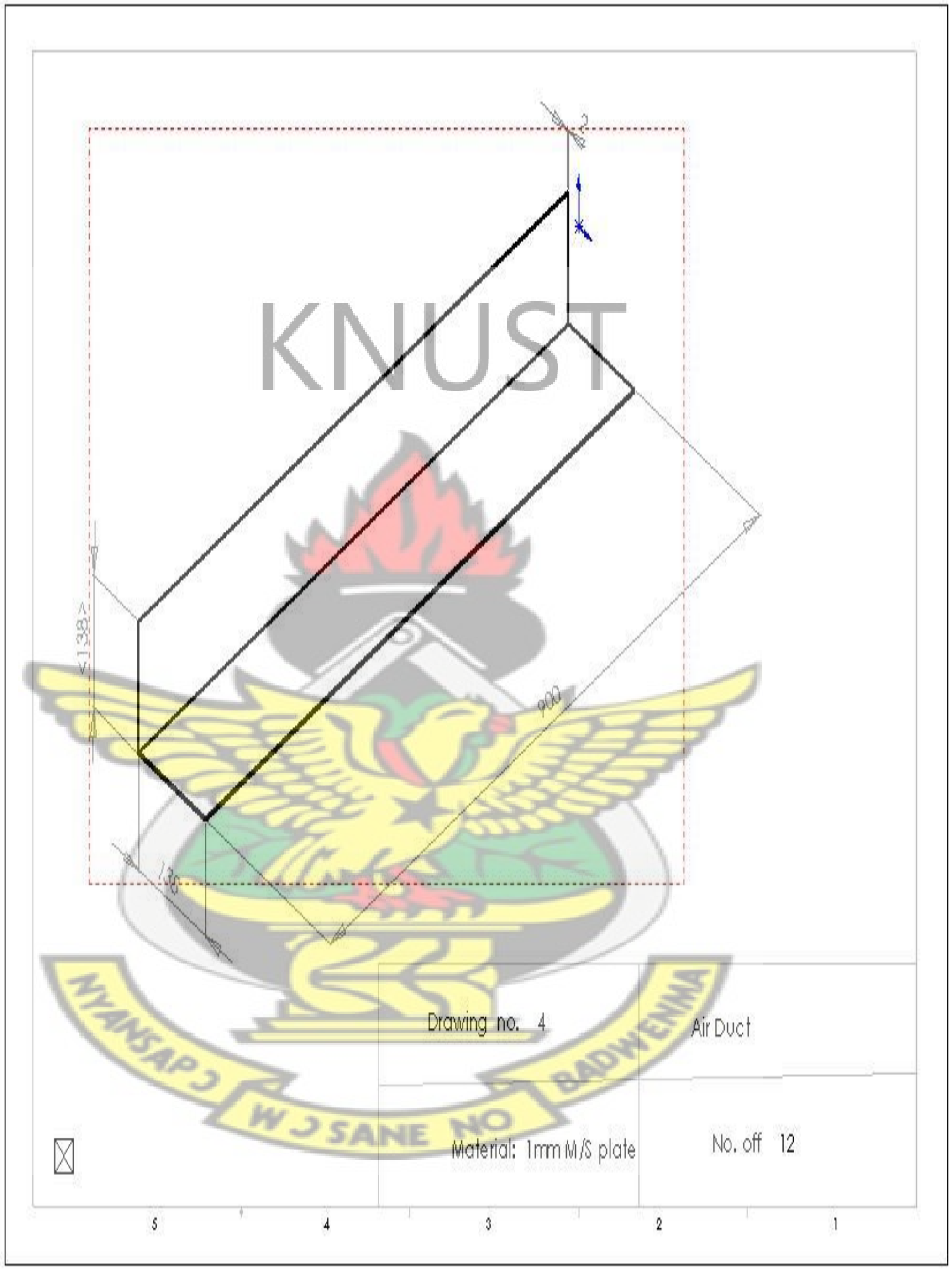


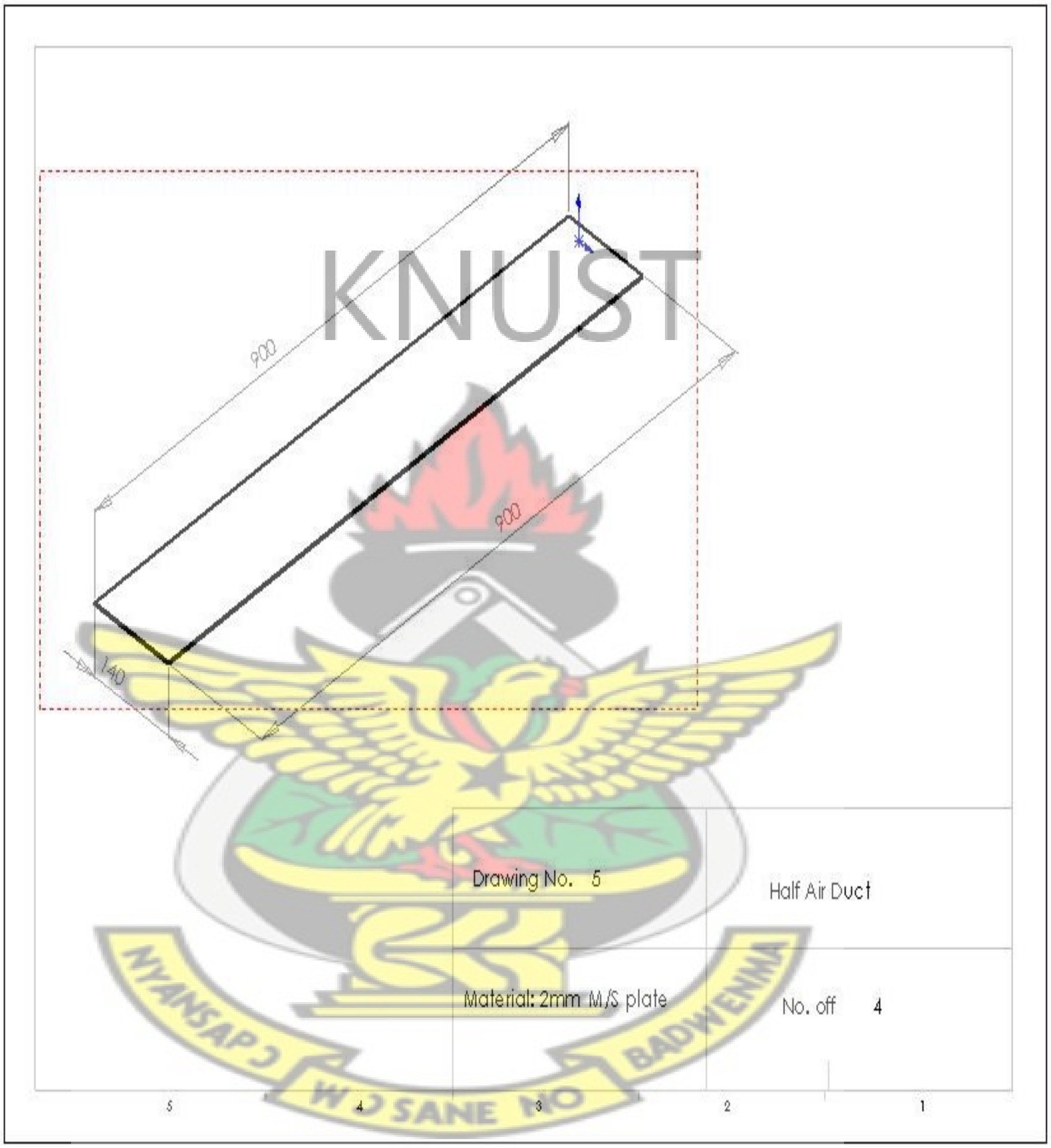


Ø17
70
5
70
200
200
2600
1 Dryer chamber corner
No. Off: 4
Matl: Mild Steel
Drawing No. 1
Dryer Chamber Corner
Scale 1:2

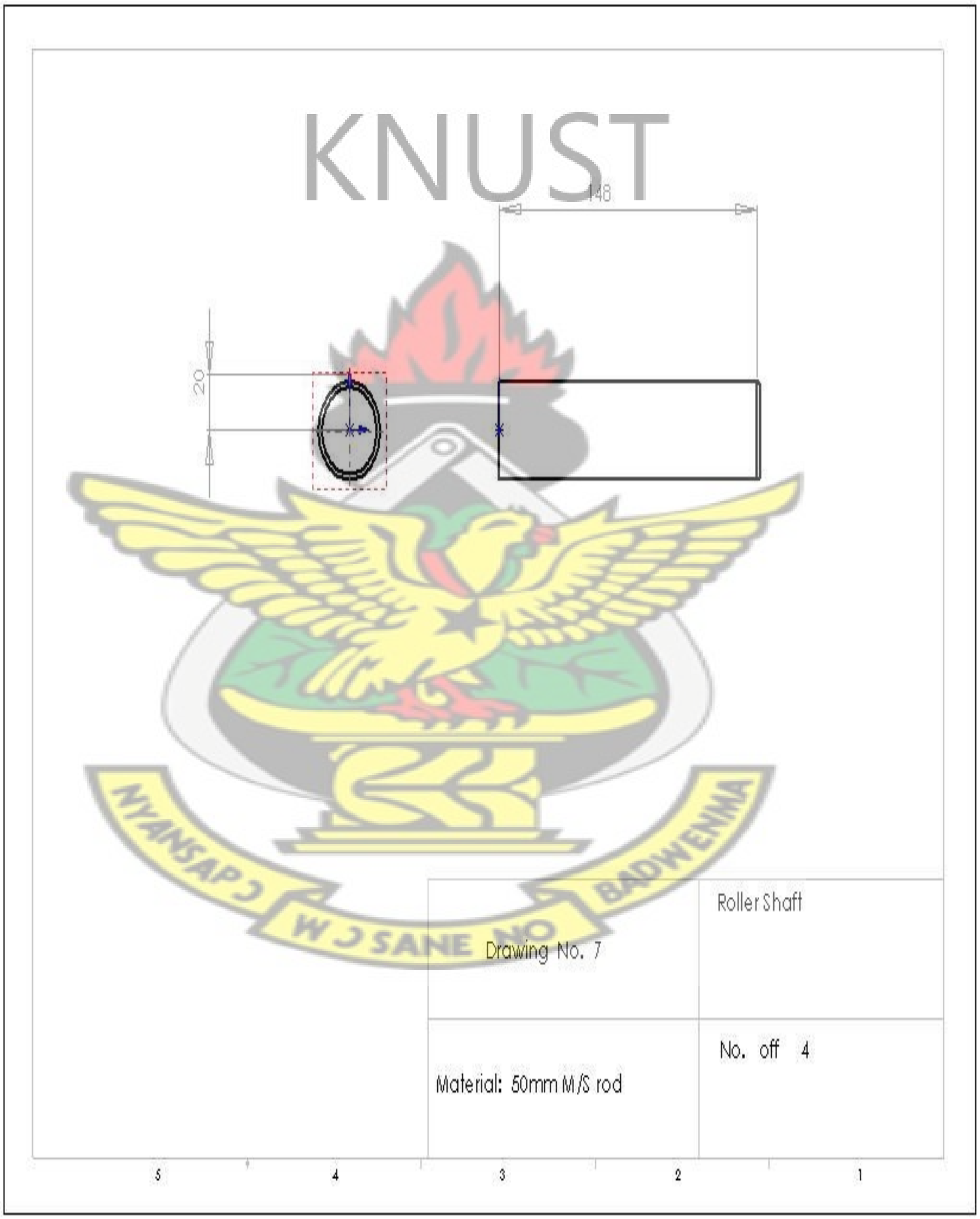

KNUST
Ø17
247.50
5
B
B
32
70
6
SECTION B-B
SCALE 1 : 2
100
70
1000
No. off 4
Scale 1:2
Stand FINAL
A4
NYANSAPƆ WƆSANE NO BADWENMA


KNUST
35
3
35
Ø17
40
SECTION A-A
900
AIR DUCT SUPPORT
A4
DRAWING NO. 4

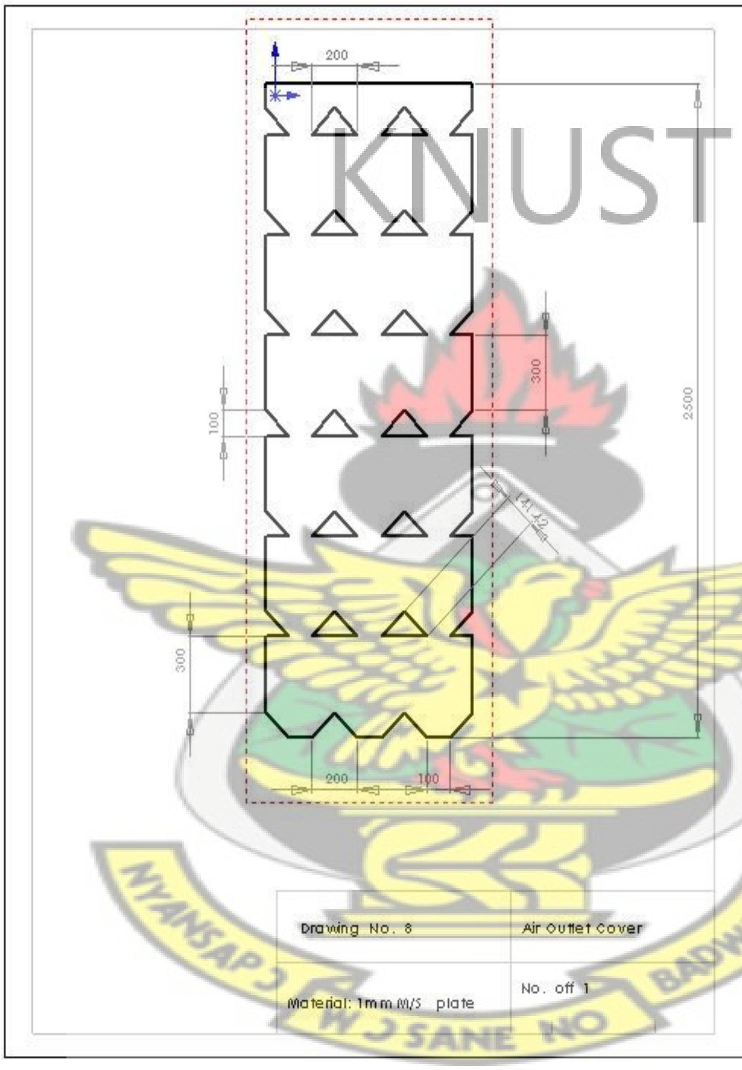

KNUST
<138>
136
900
Drawing no. 4
Air Duct
Material: 1mm M/S plate
No. off 12
NYANSAPƆ WɔSANE NO BADWENMA

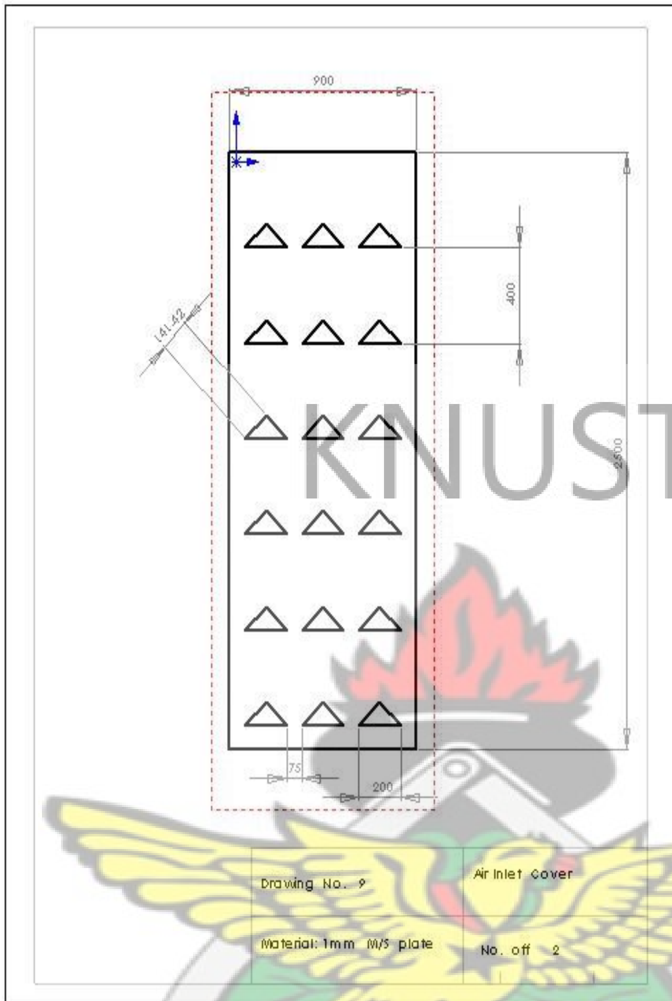


900
900
140
Drawing No. 5
Half Air Duct
Material: 2mm M/S plate
No. off 4
5
4
3
2
1



148
20
Roller Shaft
Drawing No. 7
No. off 4
Material: 50mm M/S rod


200
300
100
2500
141.42
300
200
100
Drawing No. 8
Air Outlet Cover
No. off 1
Material: 1mm M/S plate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400
141.42
2500
75
200
Drawing No. 9
Air Inlet Cover
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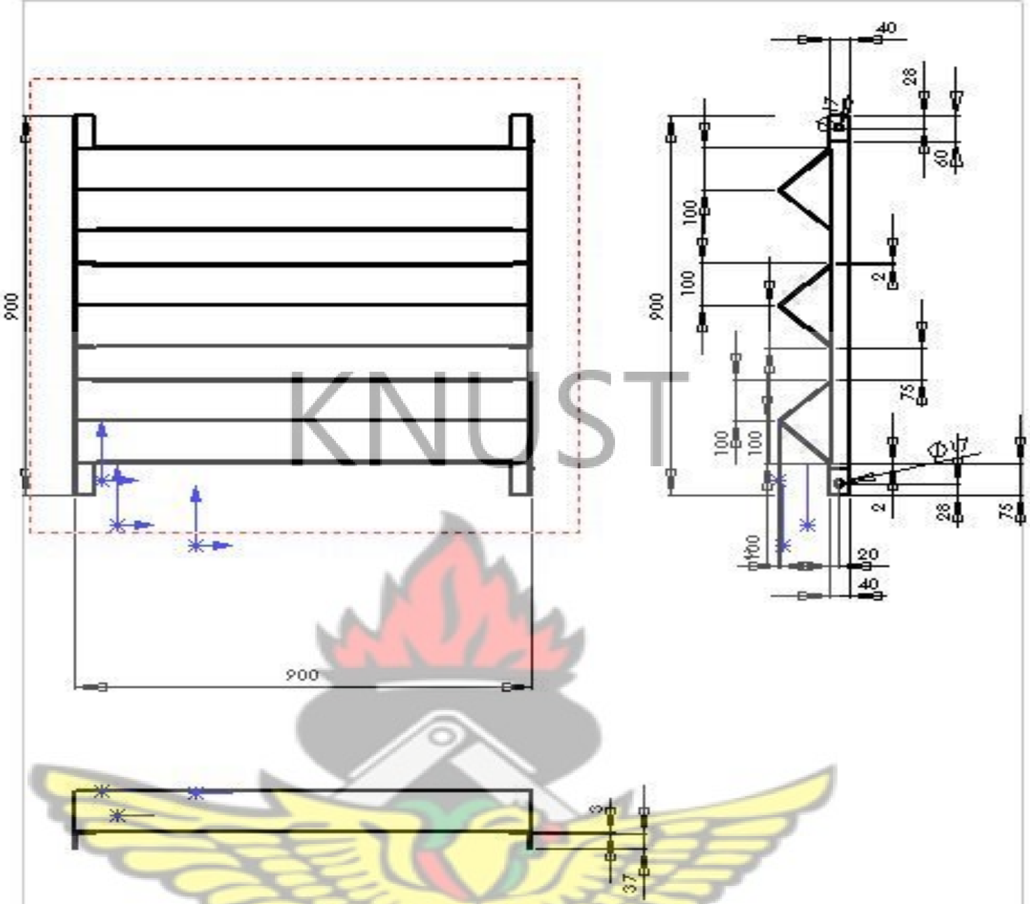
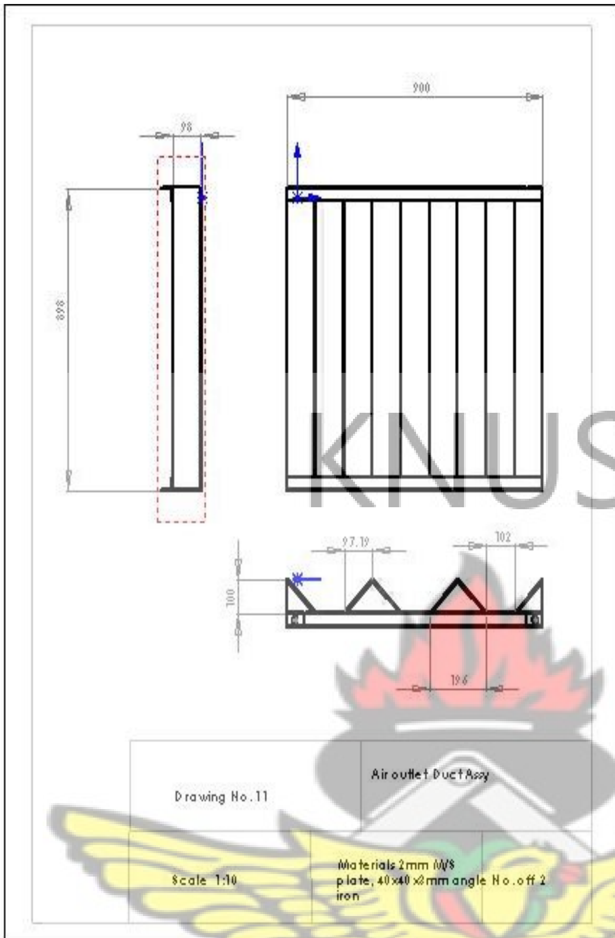
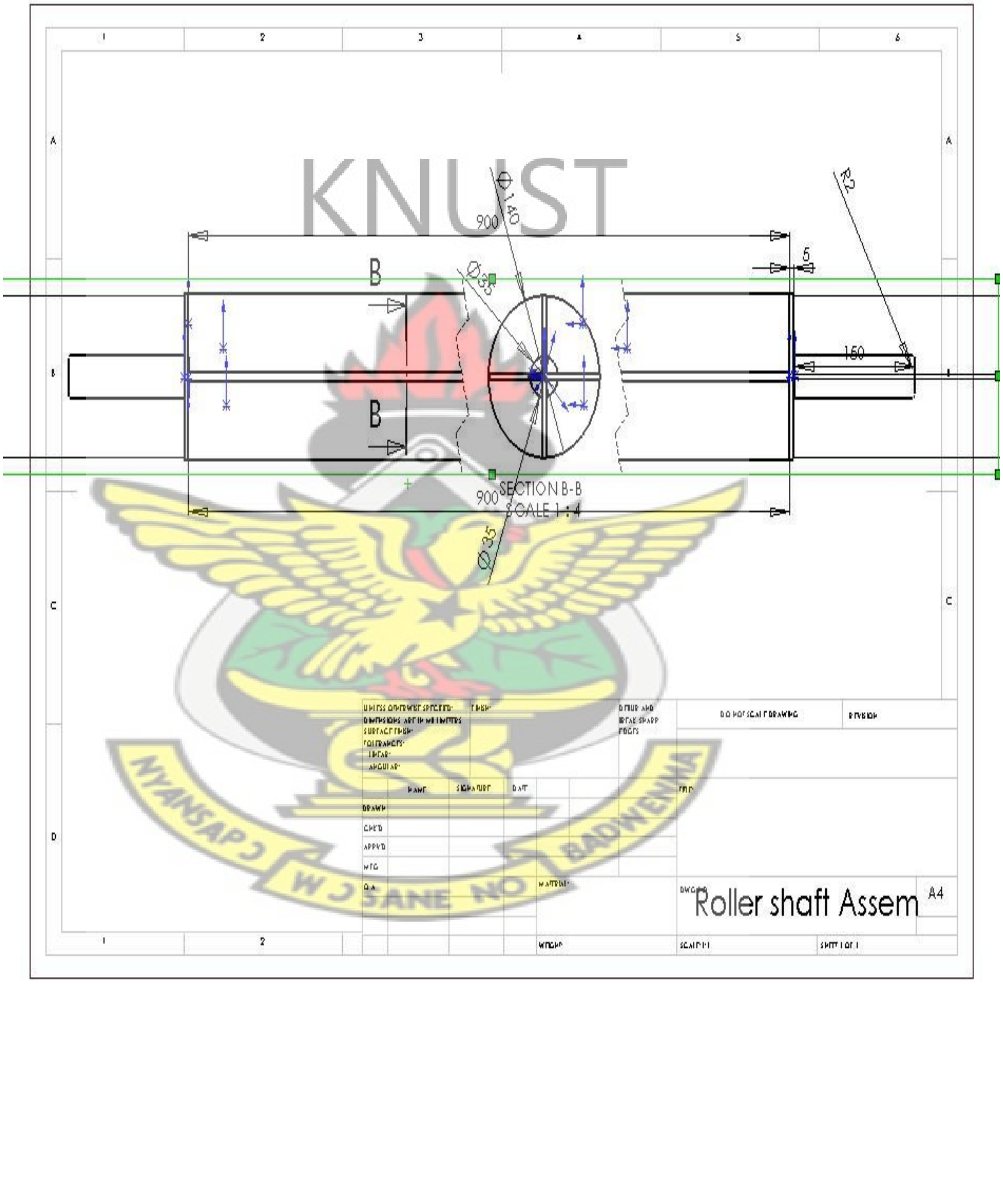
No. off 2

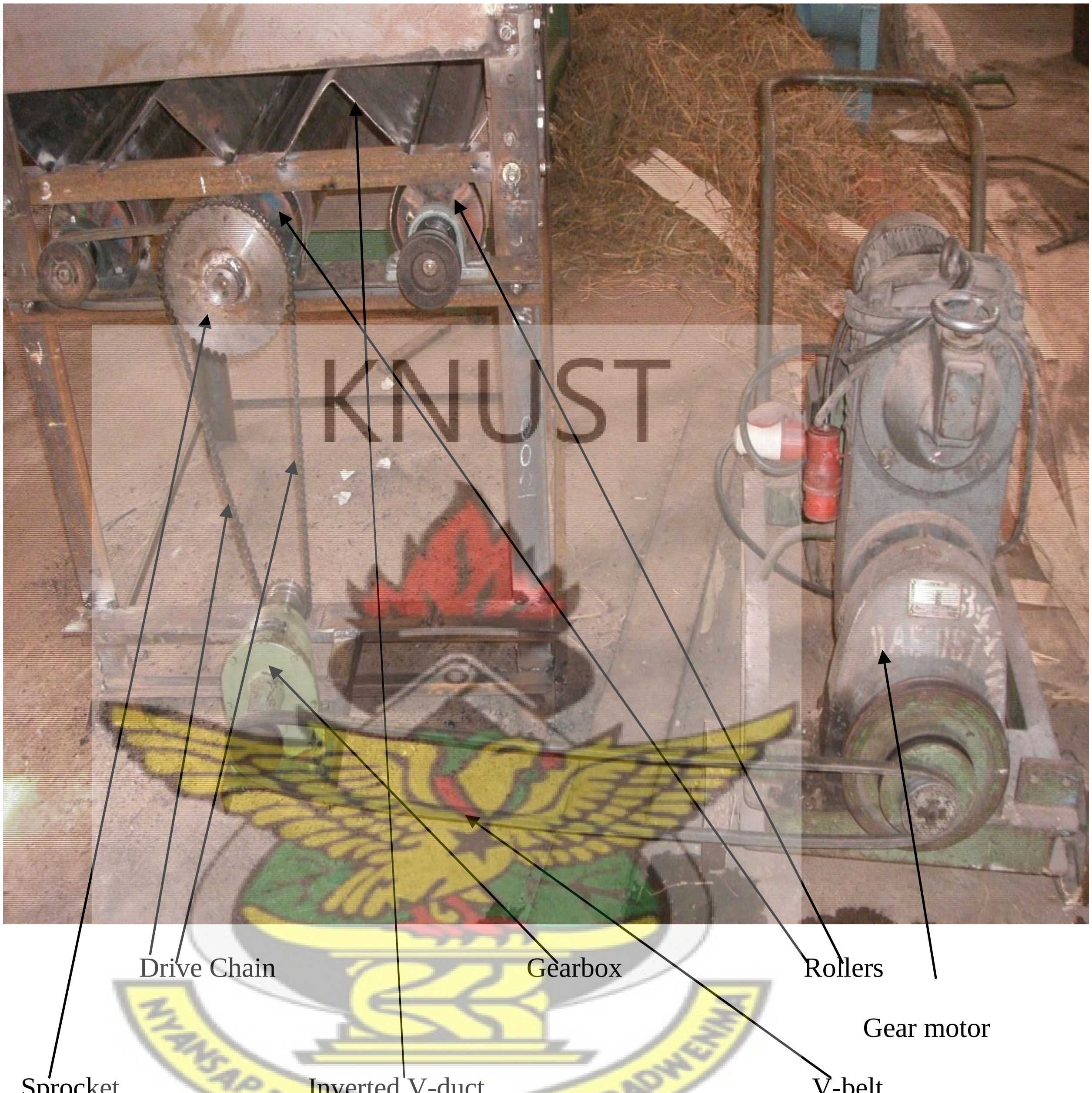


PART NO.	PART NAME	DESCRIPTION	QTY
8	INLET DUCT ASSY.	INVERTED V-DUCTS & DUCT SUPPORTS	7


900
98
898
97.19
102
100
19.6
Air outlet Duct Assy
Drawing No.11
Scale 1:10
Materials 2mm M/S plate, 40x40x3mm angle iron
No.off 2



900
Ø140
Ø35
R2
5
B
B
150
SECTION B-B
SCALE 1 : 4
900
Ø35
Roller shaft Assem
A4



DISCHARGE ROLLER DRIVE ASSEMBLY

APPENDIX II **DRYER CAPACITY DESIGN CALCULATIONS**

CROSS-SECTION (0.9M X 0.9M) X250 KG

Calculations

Design of a continuous flow-mixing type Dryer of 250kg holding capacity with paddy at 14% m.c. (wb), 16.28% db. Data for grain air parameters are as follows:

Ambient air temperature = 30^0 C

Rh of ambient air = 70%

Initial m.c. of paddy =30% wb (42.86% db)

Final m.c. of paddy = 14% wb (16.28% db)

Grain inlet temp. = 30^0 C

Grain outlet temp. = 45^0 C

Heated air temp. = 60^0 C

Exhaust air temp. = 33^0 C

Latent heat of water vapour = 600 kcal/kg

Cross-section of dryer = 1.2 x1.2 m^2

Air velocity in the air ports = 5 m/s

Pitch of air ports = 30 cm

Row to row distance of air ports = 20 cm

Grain residence time = 30 min.

Air flow requirements:

Bone-dry paddy, w_d =250(1 – 0.14) =215 kg

Initial m.c. 30% wb =42.857% db

Final m.c. = 14% wb = 16.279% db

Thus mass of moisture removed, $w_w = w_d (mc_1 - mc_2) = 215 (0.42857 - 0.16279)$

$= 215 \times 0.26578 = 57.1427$ kg

From the psychrometric chart, absolute humidity of ambient air at 30^0 C, H_1 =0.019 kg/kg

Let m_a be the rate of air supply in kg/min. Heat supplied by the drying air, q_a is given by

$$q_a = (0.24 + 0.45H_1)\, m_a (T_{a1} - T_{a2})$$

$$= (0.24 + 0.45 \times 0.019)\, m_a (60 - 33) \times 180$$

$$= 1208.099 m_a \quad \ldots\ldots (e)$$

where T_{a1} and T_{a2} are temperatures of inlet and exhaust air respectively, t , the total drying time, (min), for drying of the product is the heat utilised.

Heat utilised:

(i) Sensible heat of grain: $q_p = w_d C_{pp} (T_{p2} - T_{p1})$

$= 215 \times 0.4 (45 - 30) = 1290$ kcal

(ii) Sensible heat of water: $q_w = m_w C_{pw} (T_{p2} - T_{p1})$

$= w_d\, mc_1 C_{pw} (T_{p2} - T_{p1})$

$= 215 \times 0.42857 \times 1.0 (45 - 30) = 1382.138$ kcal

(iii) Latent heat of water of vaporisation: $q_L = m_w L_v$

$= w_d (X_2 - X_1)$

$= 215 (0.42857 - 0.16279)$

$= 34,285.5$ kcal

Thus total heat utilised; $q_a = q_p + q_w + q_L + q_{10\%}$

where $q_{10\%}$ is the heat loss due to radiation and other reasons and is assumed to be about 10% of the total heat required for drying product. Therefore,

$$q_a = 1.1 (q_p + q_w + q_L) = 1.1 (1290 + 1382.138 + 34,285.5)$$

$$= 1.1 (36,950.888)$$

= 40,645.977 kcal……………………………………………………………(f)

(e) = (f) => $1208.099m_a = 40,645.977$

$m_a = 33.6446$ kg/min.

≈ **34 kg/min.**

From the psychrometric chart, specific volume of ambient air at 30^0 C db is 0.88 m^3/kg.
Thus volume of air required, V_a = 33.6446 kg/min x 0.88 m^3/kg

= 29.607 m^3/min.

≈ 30m^3/min

Height of dryer:

Velocity of air inside air duct, v_e = 5m/s

Total cross-sectional area of ducts required = $\frac{vol.of\ air\ reqd.}{velocity\ of\ air}$

$= \frac{29.607\ m3\ x1s}{60\ s\ x\ 5\ m}$

$= 0.09869m^2$

Let the height of drying chamber be h_c.

Vol. of dryer, V = (vol. of drying chamber) - (vol. of ducts)

= $(0.9 \times 0.9 \times h_c) - 0.09869 \times 0.9$

= $0.81h_c - 0.088821\ m^3$ ……………………………………..(e)

The holding capacity the dryer is given as 1 tonne of paddy at 14% m.c. (wb). The bulk density of paddy at 14% m.c. is 578.9 kg/m^3.

Hence vol. V = $\frac{250}{578.9}$ = $0.43185m^3$ ………………………………………….(f)

Eqns (e) = (f) => $0.81h_c - 0.088821 = 0.43185$

$0.81h_c = 0.52071$

$h_c = 0.643$ m

$h_c \approx 0.64m$

Air Ducts requirements

Let the duct pitch be 0.30 m, and row to row pitch be 0.20 m.

Then if height of drying chamber is 1.50 m, the number of rows in 0.64 = 0.64/ 0.20m

= 3.2

≈ 4 rows

The width of dryer 0.9 m will accommodate 0.9 m/ 0.30 m = **3 ducts in each row.**

The total functional ducts for the grain drying will be, n = (no. of rows) x (no. of ducts per row)

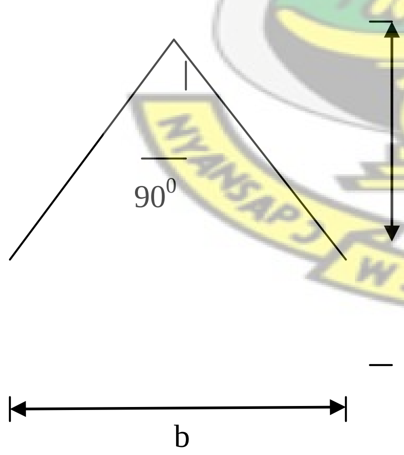
= 8 x 4 = **32 ducts**

The cross-sectional area for each duct, A will be A = $\frac{1}{2}\frac{b}{}\left(\frac{b}{2}\right)$. (see the inverted v below)

Thus A = $b^2/4$

But also, $A = \frac{volume \ \ air \ rate}{velocity \ \ x \ no.of \ ducts}$

$= V_a / vn$



$= \frac{118m3}{5\frac{m}{s}x60 \ x \ 32}$

= $0.0122917 \ m^2$

Thus $b^2 / 4 = 0.0122917$

b = 0.2217m

≈ 0.22m = 22cm

⇨ **b/2 = 0.11m =11cm**

Discharge Rollers requirements

Dimensions of discharge rollers for the controlled grain discharge are:

Flute diameter = 70mm

No. of discharge rollers = 3

Dia. Of shaft of rollers = 25mm

Vol. discharge by each roll, $V_r = \pi/4 (D_o^2 - D_i^2) L$, where D_o = flute diameter

D_i = shaft diameter

L = side of dryer

$$V_r = \pi/4(0.14^2 – 0.035^2)x0.9$$

$$= 0.0.0129885 \text{ m}^3$$

For 3 rollers, $V_r = 0.038966\text{m}^3$

Weight of paddy discharged by rollers = V_r x grain bulk density

$= 0.038966\text{m}^3 \text{ x}578.9 \text{ kg/m}^3$

≈ 22.557kg/rev

Now residence time of grain discharge = 15 min.

Grain discharge rate, R_g = 250 kg / 15 min.

= 16.6667kg /min.

Roller speed required, $\omega = \frac{Grain\ discharge\ rate, R_g}{Weight\ of\ paddy\ dicharged\ by\ rollers} = \frac{16.6667\, kg/min}{22.557\frac{kg}{rev}}$.

= 0.7388 rpm

≈ 1.0 rpm

Power Requirements

Static Pressure drop:

Surface area of plenum chamber, A = 0.7 m x 0.772m = 0.5404 m^2

Area through which air passes is = Area through which air passes

= 6x (area of triangles)

= 6 x 1/2x 0.1m x 0.1m

= 0.03m^2

Air requirement per m^2 = (30m^3 / min) / 0.03m^2 = 1000 m^3 / min m^2

From Shedds curve for 38.37m^3/ min m^2 for a depth of 0.305m = 9.24 cm.

By interpolation for 131.111 m^3 /min m^2 = (104.889 /38.37)x 9.24 = 25.258 cm.

Therefore pressure drop ΔP = (25.258 x 0.20) / 0.305 = 16.563 cm.

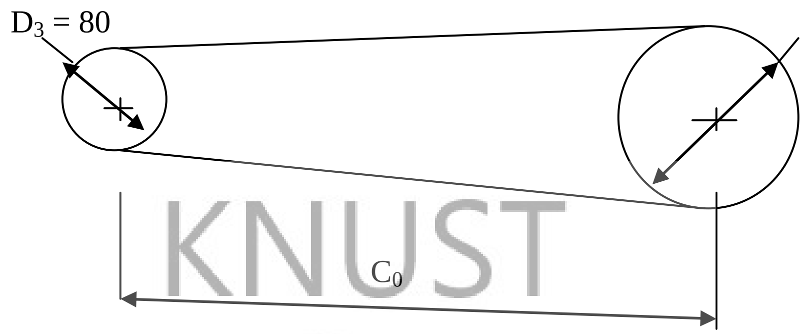
For the density of 1.13 m^3/ kg, pressure in air column is = $\frac{16.563\ cm}{100\ cm/m} \times \frac{1000}{1.13}$ = 146.57m

Power is given by P = $\frac{\Delta p\ ma}{4500} = \frac{146.57\ x\ 134.6}{4500}$ **= 4.38hp = 3.29 kW**

APPENDIX III DRYER ELEMENTS DESIGN CALCULATIONS

Drive from gearbox motor to reduction gear box:

D_4 = 147



The belt length between gearbox motor and the reduction gearbox, L_0 is given by

$$L_0 = 2C_0 + 1.57\,(D_4 + D_3) + \frac{(D_4 - D_3)^2}{4C}$$

Where, C_0 = centre distance between pulleys = 1200mm

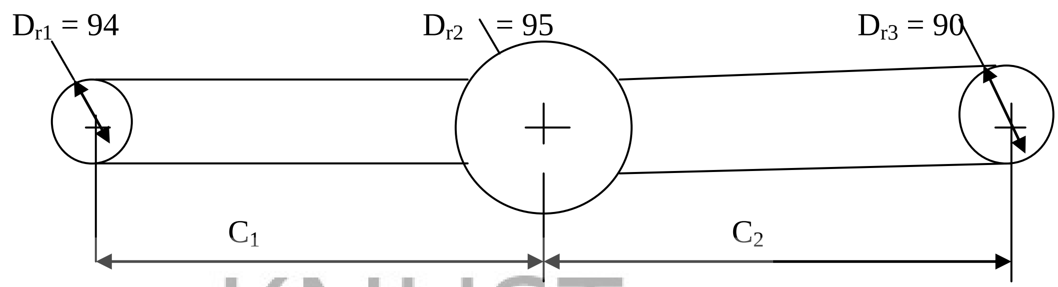
D_3 = diameter of reduction gear box = 80mm

D_4 = diameter of gearbox motor = 147mm

Substituting the values, $$L_0 = 2 \times 1200 + 1.57\,(147 + 80) + \frac{(147 - 80)^2}{4 \times 1200}$$

L_0 = 2757 mm

Belt lengths between rollers:

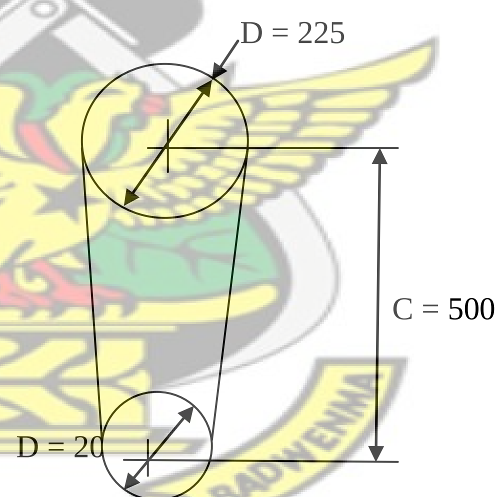


$$L_{01} = 2C_1 + 1.57(D_{r2} + D_{r1}) + \frac{(D_{r2} - D_{r1})^2}{4C}$$

$$= 2x300 + 1.57(95 + 94) + \frac{(95-94)^2}{4 \; x \; 300} = 897mm$$

Similarly, L_{02} = 890mm, where L_{01} and L_{02} are roller belt lengths.

Chain drive: (Gearseds,2010)

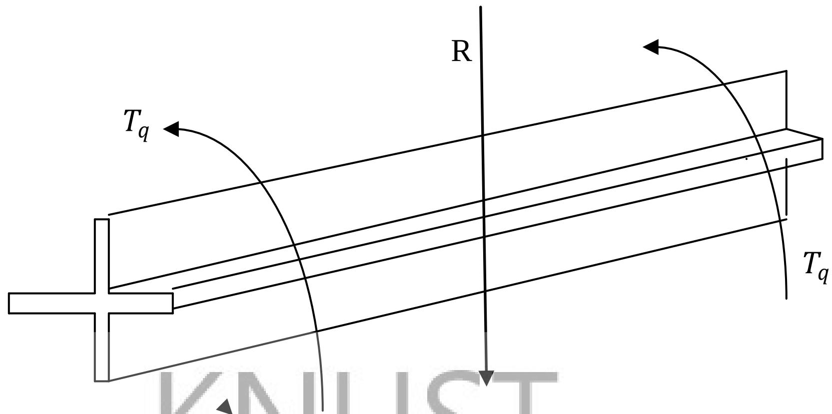


The length of the chain is given by $L = 2C + \frac{N+n}{2} + \frac{(N-n)^2}{4\pi^2 C}$

Substituting, $L = 2 \text{ x } 500 + \frac{54+20}{2} + \frac{(54-20)^2}{4\pi^2}$

L = 1376 mm

Torque on rollers:



Let the torque on the rollers be T, and the resistance offered by the paddy rice to be rolled be R. The torque is given by $T_q = \frac{60P}{2\pi n_r}$, where P = power = 3kW

n_r = rpm of rollers = 2 rpm,

Substituting, $T_q = \frac{60\ x\ 3000}{2\ x\ \pi\ x\ 2}$ = **14.32kNm**

The resistance offered by the paddy rice, R is given by $R = \frac{2\pi d^2}{4} l\ \rho_b g.$

Work done to overcome the resistance is given by W_r = R d/2

$$= \frac{2\pi d^3}{8} l\ \rho_b g.$$

Where d = diameter of roller = 0.14m

ρ_b = paddy bulk density at 14% mc = 578.9 kg/m^3

l = length of roller = 900mm

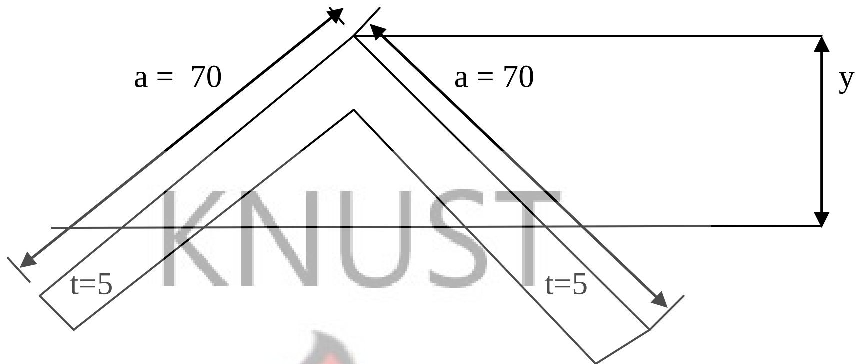
g = acceleration due to gravity 9.81 m/s^2

Substituting, $W_r = 2\pi \frac{0.14^3}{8}\ x\ 0.9\ x\ 578.9\ x\ 9.81$

W_r = 12.24 Nm, therefore for 3 rollers, **W_r = 36.72 Nm**

Thus the rollers will be able to discharge the paddy rice easily.

Buckling of the corners of the dryer:



where a = width of angle iron = 70mm

t = thickness = 5mm

y = distance from neutral axis to extreme fibre.

Cross-sectional area of angle iron, A = t (2a – t)

= 5 (2x70 – 5)

= **675 mm²**

$$y = \frac{a^2 + at - t^2}{2\,(\,2a - t\,)\cos 45°} = \frac{70^2 + 70\,x\,5 - 5^2}{2\,(\,2x70 - 5)\cos 45°}$$

y = 27.38mm = **27mm**

Moment of inertia, $I = \frac{A}{12}\left[\,7\,(a^2 + b^2) - 12y^2\,\right] - 2ab^2(a - b),$

b = a-t

i.e. $I = \frac{675}{12}[\,7(\,70^2 + 65^2\,) - 12 \text{ x } 27^2\,] - 2 \text{ x } 70 \text{ x } 65^2\,(70 – 65\,)$

I= **143393mm⁴**

From the secant formula for eccentric loading of columns, the maximum compressive stress on the corners is given by

$$\sigma_{max} = \frac{P}{A}\left[1 + \frac{ey}{r^2}\sec\left(\frac{l}{2r}\sqrt{\frac{P}{AE}}\right)\right] \text{.....(i)} \quad \text{(Gere, 2004)}$$

where, P = force (load) on the members, = 6591.409 N

A = cross-sectional area = 675mm^2

e = eccentricity = $0.9\sqrt{2}\ m$

r = radius of gyration, = $\sqrt{[\frac{I}{A}]}$ = 14.57mm

l = original length of column= 3.5m

E = modulus of elasticity, = 200MPa

y = dist. From neutral axis to the outer fibre of column = 27mm

Substituting these values into (i) above,

$\sigma_{max} = 9.7667x\ 10^6\ Pa$

= **9.7667 MPa**

The yield strength of mild steel is 248 MPa. (Gere, 2004) Therefore the 70 x 70 angle irons will not fail by buckling.

APPENDIX IV Dryer Evaluation Data

MACHINERY DATA

Gear motor: Power 3kW
Input speed 1400 rpm
Output speed 169 to 990 rpm

Blower:
speed 2800 rpm
Pressure developed 2200 Pa
Volumetric discharge 19 cu. Metres/min.

Gear box: speed ratio 900 / 24

Sundrying (control) **Date: 22nd April, 2011**

Date: 22nd April, 2011

Room Temp. °C	Ambient (outside) Temp. °C	Time (Hours GMT)	Moisture Content %
35	47.5	1000	Initial mc =22.7%
	38	1100	20.1
	44	1200	17.3
	47.5	1300	15.1
	46	1400	14.2
	45	1500	**11.8%**

First consignment paddy

Date: 21st April, 2011 **Date: 21st April, 2011**

Mass 176 kg

Initial moisture content 22.7%

It was then spread in the room from 22nd to 28th April, 2011.

Drying started on 28th April, 2011

Moisture content at the start was 17.9% at the start was **19.7%**

Pass No. One	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp. °C DB**	**Time (Hours GMT)**	**Moisture Content ,%**
	30	**47**	**46.5**	**09:00**	**19.7**
	30	47	37	09:10	
	30.5	47	37	09:16	
Resident Time	30.5	47	37	09:22	
t_r = 36min	31	47	36.5	09:28	
	31	47	37	09:34	
	31	47	37.5	09:40	

mc = 16.7% , mc = 16.6% , mc = 16..3% , mc = 16.4%

Av. Mc = 16.5% **16.5%**

mc= 16.4%, Av. MC= 16.5% **16.50%**

Pass No. Two	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp. °C DB**	**Time (Hours GMT)**	**Moisture Content ,%**
	32	48	39	10:25	
	32	48	39	10:31	
Resident time,	32	48	39	10:37	
tr = 36min.	33	48	39	10:43	
	33	48	39	10:49	
	33	48	39.5	10:55	**15.70%**

mc1= 16.0, mc2 = 15.7, mc3 = 15.5, mc4 = 15.6 Thus mc av. = 15.7%
15.7%

Pass No. THREE	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp. °C DB**	**Time (Hours GMT)**	**Moisture Content ,%**
	32	49	40	12:20	
	32	49	40	12:26	
	33	49	40	12:32	
tr = 36min	34	49	40	12:38	

	34	49.5	40	12:44	
	34	49.5	40.5	12:50	**14.40%**

mc1 = 14.5, mc2 = 14.4, mc3 = 14.4, mc414.3 mc av. = 14.4
14.4% 14.40%

Av, mc = 14.4%%

Pass No. **FOUR**	**Ambient Temp.** **°C**	**Inlet Temp.** **°C**	**Outlet Temp.** **°C DB**	**Time (Hours GMT)**	**Moisture Content ,%**
	34	49	41	13:34	
	35	49	42	13:44	
	35	49	42	13:54	
tr=36min	35	48	43	14:04	
	34	49	43	14:14	
	34	49	43	14:20	**13.50%**

mc1 = 13.6, mc2 = 13.5, mc3 = 13.5, mc4 = 13.5, Σmc
= 54.2, mc. Av. = 13.5 **13.5%** 13.50%

av, mc = 13.5%

Ta = ambient temperature Ti = inlet temperature

Todb = outlet dry bulb temperature Towb = outlet wet bulb temperature

Rho = outlet air relative humidity Rha = ambient relative humidity

ANALYZED DATA FOR GRAPHS

Ta	Ti	Todb	Towb	Rho	Rha
32	**47**	**46.5**	**26**	**20**	**60.6**
30	47	37	30	60	60.6
30.5	47	37	29	55	60.9
30.5	47	37	29.5	57.4	60.9
31	47	36.5	28	52.2	58.4
31	47	37	28	50.3	58.4
31	47	37.5	27.5	46.2	58.4
32	48	39	**27.5**	41.1	59.2
32	48	39	27.5	41.1	59.2
32	48	39	27	35.2	59.2
33	48	39	26	35.2	57.2
33	48	39	26	33.8	57.2
33	48	39.5	26	32.4	57.2
32	49	40	**26**	32.4	59.2
32	49	40	26	30.6	59.2
33	49	40	25.5	30.6	59.9
34	49	40	25.5	30.6	58.4
34	49.5	40	25.5	27.7	58.4
34	49.5	40.5	25	29.9	58.4
34	49	41	**26**	27.5	57
35	49	42	26	27.5	58.6
35	49	42	26.5	27.5	58.6
35	48	43	26.6	26.8	58.2
34	49	43	26	25.3	59.5
34	49	43	26	25.3	59.5

The following sample calculations were done to obtain the table below:

From $P_{sa} = \frac{6\ x\ 10^{25}}{(T_a + 273.15\ )^5} \exp[\ \frac{-6800}{T_a + 273.15}\ ]$, and for T_a = 30°C, then

P_{sa} = 4247.60 Pa.

Also, from $X_a = \frac{0.622\ x\ Rh_a P_{sa}}{P_{atm} - Rh_a P_{sa}}$, and for

Rh_a = 57.7%, P_{sa} = 4247.60 Pa, and P_{atm} = 101325 kPa, then

X_a = 0.015418.

CONSIGNMENT 1

Ta	tr	Psa	Xa	Todb	Psodb	Xodb
30	0	4247.6	0.01621	46.5	10373.25	0.013
30	18	4247.6	0.01621	37	6286.95	0.02191
31	30	4498.02	0.016904	37	6286.95	0.02015
31	42	4498.02	0.016904	37.5	6460.53	0.01888
32	54	4761.16	0.0178	39	7006.33	0.01819
33	66	5037.56	0.0182	39	7006.33	0.01552
33	78	5037.56	0.0182	39.5	7196.89	0.01465
32	90	4761.16	0.0178	40	7391.91	0.0142
34	102	5327.76	0.0197	40	7391.91	0.0142
34	114	5327.76	0.0197	40.5	7591.48	0.01425
35	126	5632.33	0.02094	42	8218.28	0.01419
35	138	5632.33	0.0208	43	8660.48	0.01375
34	150	5327.76	0.02009	43	8660.48	0.01375

Paddy Rice Consignment 2

Mass of paddy 250 kg

Date: 3rd May, 2011

Initial moisture content from farm = 20.9%

Consignment 2

Pass No. ONE	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp. °C DB	Outlet Temp. °C WB	Time Hours (GMT)	Moisture Content %
	29	46	30	25.5	09:30	Initial mc
	29	46	31	25.5	09:36	20.90%
	31	46	31.5	25	09:42	
tr = 36min.	32	46	31.5	25	09:48	
	32	47	32	24.5	09:54	
	32	47	32	24	10:00	
	33	47	32	25	10:06	**19.00%**

mc1 = 19.3, mc2 = 18.6, mc3 = !9.5, mc4 = 18.6, Σmc = 76,

Thus mc av. = 19.0 **19.0%** 19.00%

Thus ma av. = 19.0%

Pass No. TWO	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp. °C DB	Outlet Temp. °C WB	Time Hours (GMT)	Moisture Content %
					10:40	
	33	49	33	25	10:46	
	33	49	34	23	10:52	
tr = 36min.	33	49	34.5	24.5	10:58	
	33	49	35	24	11:04	
	34	48	36	25.5	11:10	
	34	49	35	25	11:16	**18.40%**

mc1 = 18.7, mc2 = 18.5, mc3 = 18.5, mc = 17.9, Σmc
mc2 = 18.5, = 73.6 Thus mc av. = 18.4 **18.4%**

Thus mc av. = 18.4% 18.40%

Pass No. THREE	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp. °C DB	Outlet Temp. °C WB	Time Hours (GMT)	Moisture Content %
	34	49	41	22.5	11:40	
	34	49	41	23	11:46	
	35	49	42	23	11:52	
tr = 36min.	35	49	42	23	11:58	
	35	49	43	26.5	12:04	
	35	49	43	26.5	12:10	**17.60%**

mc1 = 17.7, mc2 = 17.6, mc3 = 17.6, mc4 = 17.6,
mc5 = 17.5, Σmc = 88.0

Thus mc av. = 17.6%

Pass No. FOUR	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp. °C DB	Outlet Temp. °C WB	Time Hours (GMT)	Moisture Content %
	35	49	44	27	12:36	
	35	49	45	28.5	12:42	
	35	48	45	26	12:48	
tr = 36min.	34	49	46	27	12:54	
	34	49	46	27	13:00	
	33.5	48.5	47	28	13:06	**15.40%**

mc1 = 15.5, mc2 = 15.5, mc3 = 15.5, mc4 = 15.3, mc5 = 15.3, mc6 = 15.2

, Σmc = 92.3 Thus mc av. = 15.4%

Pass No.	Ambient Temp.	Inlet Temp.	Outlet Temp.	Outlet Temp.	Time Hours	Moisture Content
FIVE	°C	°C	°C DB	°C WB	(GMT)	%
	34	50	48	26	13:37	
	34	50	48	27	13:43	
	34	50	47	28.5	13:49	
tr = 36min.	34	50	48	28	13:55	
	33	50	48	27	14:01	
	33.5	50	49	26	14:07	
	33	50	49	26	14:13	**13.30%**

mc1 = 13.4, mc2= 13.4, mc3= 13.3, mc4= 13.3, mc5= 13.3, mc6= 13.2

Σmc = 79.9, Thus mc av. = 13.3%

Ta	Ti	Todb	Towb	mc	Rho	Rha	tr
29	46	46	26.5	20.9	20.9	65.9	0
29	46	30	25.5		69.6	65.9	12
29	46	31	25.5		64.2	65.9	18
29	46	31.5	25		58.8	65.9	24
31	46	31.5	25		58.8	67.1	30
32	47	32	24.5		53.2	62	36
32	47	32	24		51.1	62	42
32	47	32	25	19	56.4	62	48
33	49	33	25		52	62.6	54
33	49	34	23		38.6	62.6	60
33	49	34.5	24.5		43.6	62.6	66
33	49	35	24		39.6	62.6	72
33	48	36	25.5		42.7	62.6	78
34	49	35	25	18.4	44	60.5	84
34	49	41	22.5		18.7	60.5	90
34	49	41	23		20.2	60.5	96
34	49	42	23		18.3	60.5	102
35	49	42	23		18.3	61.2	108
35	49	43	26.5		26.8	61.2	114
35	49	43	26.5	17.6	26.8	61.2	120
35	49	44	27		26.2	61.2	126
35	49	45	28.5		28.6	61.2	132
35	48	45	26		21.3	61	138
35	49	46	27		22.3	61	144
34	49	46	27		22.3	63.2	150
34	48.5	47	28	15.4	23.2	63.2	156
33.5	50	48	28		21.4	63	162

34	50	48	28		21.4	63.2	168
34	50	47	28.5		23.2	63.2	174
34	50	48	28		21.4	63.2	180
34	50	48	28		21.4	63.2	186
33	50	49	28		20	63	192
33	50	49	28	13.3	20	63	198

The following sample calculations were done to obtain the table below:

From $P_{sa} = \frac{6\ x\ 10^{25}}{(T_a + 273.15\ )^5} \exp[\frac{-6800}{T_a + 273.15}]$, and for T_a = 30°C, then

P_{sa} = 4247.60 Pa.

Also, from $X_a = \frac{0.622\ x\ Rh_a P_{sa}}{P_{atm} - Rh_a P_{sa}}$, and for

Rh_a = 57.7%, P_{sa} = 4247.60 Pa, and P_{atm} = 101325 kPa, then

X_a = 0.015418.

Ta	tr	Psa	Xa	Todb	Psodb	Xodb
29	0	4009.38	0.01665	46	10112.07	0.01325
29	18	4009.38	0.01665	30	4247.6	0.01857
31	30	4498.02	0.0191	31	4498.02	0.01825
32	42	4761.16	0.01866	31.5	4627.97	0.01708
33	54	5037.56	0.01998	32	4761.16	0.0153
33	66	5037.56	0.01998	33	5037.56	0.01651
33	78	5037.56	0.01998	34.5	5478.21	0.01502
34	90	5327.76	0.020436	36	5951.86	0.016
34	102	5327.76	0.020436	41	7795.67	0.00907
35	114	5632.33	0.02191	42	8218.28	0.00937
35	126	5632.33	0.02191	43	8660.48	0.01458
35	138	5632.33	0.02191	44	9123	0.01503
34	150	5327.76	0.02138	45	9606.6	0.01282
33.5	162	5180.9	0.020703	46	10112.07	0.01416
34	174	5327.76	0.02138	48	11191.83	0.01506
34	186	5327.76	0.02138	47	10640.2	0.0143
33	192	5037.76	0.02011	48	11191.83	0.01506
33	198	5037.76	0.02011	49	11767.79	0.01479

Paddy Rice Consignment 3

Date: Thursday, 26th May,2011

Mass 250kg

Initial moisture content:

mc1 = 21.9

mc2 = 21.5

mc3 = 21.8 21.80%

mc4 = 21.4%

Av. Mc = 21.7%

Thus initial moisture content is **21.7%**

Pass No. ONE	**Aambient** Temp °C	**Inlet** Temp°C	**Outlet** Temp °C DB	**Outlet** Temp °C WB Hours GMT	**Time** Hours (GMT)	**Moisture** content(%)
	30	43.5	43.5	25	1038	No rice
	30	44.5	31	23	1046	inside dryer,
	30	44.5	30	24	1054	21.70%
Residence time,	30	44	30	24	1102	
tr = 48min.	31	44	30.5	24	1110	
	31	44	34	25	1118	
	31	44.5	34.5	25.5	1126	**18.90%**
	mc1 = 18.5,	mc2 = 18.6,	mc3 = 18.7,	mc4 = 19.3,	mc5 = 19.3,	mc6 = 18.9
	mc6=18.9	Σmc = 113.3	Av. Mc = 18.9%			**18.90%**

Pass No. TWO	**Aambient** Temp °C	**Inlet** Temp°C	**Outlet** Temp °C DB	**Outlet** Temp °C WB	**Time** Hours (GMT)	**Moisture** content(%)
	31	47.5	46	26	1320	No rice in dryer
	32	48	32	25.5	1328	
Residence time,	32	48	32	25	1336	
tr = 48min.	32	48	32	26.5	1344	
	31.5	48	32	25	1352	
	31.3	48	32.5	24.5	1400	
	32	47.5	34	26	1408	
	32	49	35	25	1416	**17.00%**
	mc1 = 17.3,	mc2 = 17.3,	mc3 = 16.9, Σmc = 85.2, = 17.0	mc4 = 16.3,	mc5 = 17.4 Av. Mc	**17.00%**

Pass No. THREE	**Aambient** Temp °C	**Inlet** Temp°C	**Outlet** Temp °C DB	**Outlet** Temp °C WB	**Time** Hours (GMT)	**Moisture** content(%)
	31	48	33	28	1514	
	32	46	32	28	1522	
	32	47	31	27	1530	
Residence time,	32.5	47	33	28	1538	
tr = 48min.	32.5	48	35	28.5	1546	
	33	48	34	25.5	1554	
	33	48	34	25	1602	
	33	49	34	27	1610	
	31	49	35	26	1618	**15.90%**
	mc1 = 16, mc2 = 15.4, mc3 = 16, mc4 = 16.3, Σmc = 63.7, => Av. Mc = 15.9%					**15.90%**

Electric power disruption for two days, Friday and Saturday, 27th and 28th May, 2011 respectively. So drying resumed on Thursday, 2nd June, 2011.

So drying resumed on Thursday, 2nd june, 2011

Pass No. FOUR	**Aambient** Temp °C	**Inlet** Temp°C	**Outlet** Temp °C DB	**Outlet** Temp °C WB	**Time** Hours (GMT)	**Moisture** content(%)
						Initial mc = **17.1%**
	28.5	28.5	28.5	18.5	800	0.171
	29	43	42.5	24.5	820	
	29.5	43.5	28.5	24	830	
	29	43.5	28.5	24	838	
Resident Time,	29	43	28	24.5	846	
tr = 48min.	29	43	28	25	854	
	29.5	43	29	25	902	
	29.5	43	31.5	25	910	
	29.5	43	34	26	918	
	33	44	34	26	926	
	33	46	34.5	25.5	934	**15.10%**

MC after the 4th pass: mc1 = 16, mc2 = 15, mc3 = 15.2, mc4 = 14.8, mc5 = 14.9, mc6 = 14.6, mc7 = 14.6, mc8 = 15.6

Σmc = 120.7 => Av. Mc = 15.1 15.10%

Pass No.	**Aambient**	**Inlet**	**Outlet**	**Outlet**	**Time**	**Moisture**

FIVE	Temp °C	Temp°C	Temp °C DB	Temp °C WB	Hours (GMT)	content(%)
	32	45	32.5	25	1056	
	32	45.5	32	25	1104	
	33	45	31	25	1112	
Residence time,	33	45	31	25	1120	
tr = 48min.	33.5	45.5	36.5	27.5	1128	
	34	46	40.5	28	1136	
	34	46	40	27	1144	
	33.5	46	38	26	1152	
	33.5	46	38	26	1200	
	33.5	46	40	26.5	1208	**13.70%**

MC after the fifth pass: mc1 = 13.7, mc2 = 13.4, mc3 = 13.6, mc4 = 14.1, mc5 = 13.2, mc6 = 14.1, mc7 = 14.3

		mc8 = 13.3,		Σmc = 109.7	=>	
mc6=14.1	mc7=14.3	Av. Mc = 13.7%				13.70%

Pass No.	**Aambient**	**Inlet**	**Outlet**	**Outlet**	**Time**	**Moisture**
SIX	Temp °C	Temp°C	Temp °C DB	Temp °C WB	Hours (GMT)	content(%)
	35.5 (24wb)	48	35	27	1340	
	35 (24wb)	48	33.5	25.5	1348	
	35(24wb)	48	32	25.5	1356	
Residence time,	34.5 (24wb)	47.5	33.5	26	1404	
tr = 48min.	34.5 (24wb)	47	36.5	25	1412	
	34.5 (24wb)	48	40	23.5	1420	
	35(25.5w)	48	38.5	26.5	1428	
	35(24wb)	48	38	26	1436	
	35 (25wb)	48	41.5	27	1444	
	35 (24.5wb)	48	41	27	1452	**12.40%**

Mc_1=13.1	Mc_2=13.1	Mc_3=12.3	Mc_4=12.2	Mc_5=12.0	Mc_6=12.0	
Mc_7=12.1	Mc_8=13.1	99.9	12.4			12.40%

ANALYZED FOR GRAPHING

tr	Ta	Ti	Todb	Towb	RH	MC
0	30	43	43.5	25	25	21.1
48	30	44.1	31.2	24.4	56	18.9
96	31	48	32.8	25.4	65	17
144	31	47.8	33.5	26.9	60	15.9
192	29	43	34.5	25	45	15.1
240	33.2	45.6	36	26.1	47	13.7
288	35	48	37	25.9	42	12.4

Tadb	Ti	Todb	Towb	MC	Rho	Rha	tr
							0
30	43.5	43.5	25	21.7	21.3	60.6	8
30	44.5	31	23		50	60.6	16
30	44.5	30	24		60.6	60.6	24
30	44	30	24		60.6	60.6	32
30	44	30.5	24		58.1	60.6	40
30.5	44	34	27		57.9	60.9	48
30.5	44.5	34.5	27	18.9	57.9	60.9	56
30.5	48	32	25.5		59.2	60.9	64
31	48	32	25		56.4	59.6	72
31	48	32	25		56.4	59.6	80
31	48	32	25		56.4	59.6	96
31	48	32.5	25.5		56.8	59.6	104
31	47.5	34	26.5		55.3	59.6	112
31		35	27	17	53.5	59.6	120
32	48	33	25.5		54.6	59.2	128
32	46	32	24.5		53.8	59.2	136
32	47	31	23.5		52.9	59.2	144
32	47	33	25		52	59.2	152
32	48	35	26.5		51.1	59.2	160
33	48	34	25.5		50.3	59.9	168
33	48	34	25.5		50.3	59.9	176
33	49	34	25.5		50.3	59.9	184
32	49	35	26.5	15.9	50	59.2	192
29.5	43.5	28.5	21		50.7	60.2	200
29	43.5	28.5	21		50.7	59.8	208
29	43	28	20.5		50.2	59.8	216
29	43	28	20.5		50.2	59.8	224
29.5	43	29	21		48.4	60.2	232
29.5	43	31.5	23		48.1	60.2	240

29.5	43	34	26		52.8	60.2	248
33	44	34	26		52.8	59.9	256
33	46	34.5	25.5	15.1	48.3	59.9	368
32	45	32.5	24		49	59.2	272
32	45.5	32	23.5		48.6	59.2	280
33	45	31	22.5		47.6	59.9	288
33	45	31	22.5		47.6	59.9	296
33.5	45.5	36.5	26.5		45.3	54.9	304
34	46	40	27	13.7	36.1	55.3	312
33.5	46	38	26		38.2	54.9	320
33.5	46	38	26		38.2	54.9	328
33.5	46	40	27.5		38	54.5	336
35.5	48	35	23.5		37.4	55.3	344
35	48	33.5	22.5		38	56	352
35	48	32	21.5		38.7	58.2	360
34.5	47.5	33.5	22.5		38.8	58.2	368
34.5	47	36.5	25		38.8	58.2	376
34.5	48	40	27.5		38.7	58.2	384
35	48	38.5	26		36.7	58.6	392
35	48	38	25.5		36.2	58.6	400
35	48	41.5	27.5		33.8	58.6	408
35	48	41	27	12.4	33.3	58.6	416

CONSIGNMENT 3

Ta	Psa	Xa	Todb	Psodb	Xodb	tr
30	4247.6	0.016213	43.5	8889.15	0.01168	0
30	4247.6	0.016213	30	4247.6	0.01621	24
30	4247.6	0.016213	30.5	4371.25	0.01597	40
30.5	4371.25	0.016783	43.5	5478.21	0.0201	56
31	4498.02	0.016904	32	4761.16	0.01693	72
31	4498.02	0.016904	32	4761.16	0.01693	88
31	4498.02	0.016904	34	5327.76	0.01863	104
32	4761.16	0.0178	33	5037.56	0.01736	120
32	4761.16	0.0178	31	4498.02	0.01496	136
32	4761.16	0.0178	35	5632.33	0.011818	152
33	5037.56	0.01909	34	5327.76	0.01689	168
32	4761.16	0.0178	35	5632.33	0.01778	184
29	4761.16	0.01507	28.5	3894.68	0.01236	200
29	4009.38	0.01507	28	3782.86	0.01188	216
29.5	4009.38	0.01563	29	4009.38	0.01214	232
33	4126.99	0.01909	34	5327.76	0.01776	248

32	5037.56	0.0178	34.5	5478.21	0.01668	264
33	4761.16	0.01909	32	4761.16	0.01454	280
33.5	5037.56	0.01796	31	4498.02	0.01287	296
33.5	5180.9	0.01796	40	7391.91	0.01473	312
33.5	5180.9	0.01783	38	6638.23	0.01597	328
35	5180.9	0.01998	35	5632.33	0.01321	344
34.5	5632.33	0.02021	32	4761.16	0.01152	360
34.5	5478.21	0.02021	36.5	6117.42	0.01492	376
35	5632.33	0.02106	38.5	6820.13	0.01575	392
35	5632.33	0.02106	41.5	8004.57	0.01706	408

Paddy Consignment 4 **Date: 30th May, 2011**

Mass 245kg Date:

Initial moisture content: mc1 = 26.8%, mc2 = 26.6%, mc3 = 26.7% Σmc = 80.1

Therefore Av. Mc = 26.6%

Thus Initial Mc = **26.6%**

Pass No. ONE	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp.°C DB**	**Outlet Temp.°C WB**	**Time Hours GMT**	**Moisture Content %**
						Initial mc is
	27.5(24wb)	42	42	26.5	09:30	**26.6%**
	28	42	32	28	09:40	
Residence Time,	28	42	32	27	09:48	
tr = 48min.	28	42	31.5	27	09:56	
	28	42	29.5	27	10:04	
	28	42	28.5	25	10:12	
	28	42	28	25	10:20	
	28	42	29	25.5	10:28	
	28	42	30	21	10:36	**22.30%**

moisture content after first pass: mc1 = 22. 0, mc2 = 22.0, mc3 = 22.5, mc4 = 22.3, mc5 = 22.5

Σmc = 111.3, => Av. Mc = 22.3% 22.30%

mc5=22.5

Pass No. TWO	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp.°C DB**	**Outlet Temp.°C WB**	**Time Hours GMT**	**Moisture Content %**
	30	44	30	27	1148	
Residence Time,	30	44	29	27	1156	

tr = 48min.	30	45	30	27	1204	
	30	45	30	27	1212	
	30.5	45	31	26	1220	
	30.5	45	31.5	27	1228	**19 5%**

Moisture content after 2nd pass: mc1 = 20.1, mc2 = 20.2, mc3 = 18.9, mc4 = 19.2, mc5 = 19.3

Σmc = 97.7, thus Av. Mc = 19.5%

Pass No. **THREE**	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp.°C DB**	**Outlet Temp.°C WB**	**Time Hours GMT**	**Moisture Content %**
	31.5	46	32	26.5	1328	
	31	46	32	26.5	1336	
	31	45	34	27.5	1344	
	31	44.5	34.5	27	1352	
	31	45	34	27	1400	
	31	45	34	27	1408	**17.60%**

Moisture content after 3rd pass: mc1 = 18.1, mc2 = 17.5, mc3 = 17.5, mc4 = 17.2, mc5 = 17.7

Σmc = 88.0 , thus Av. Mc = 17.6% 17.60%

Pass No. **FOUR**	**Ambient Temp. °C**	**Inlet Temp. °C**	**Outlet Temp.°C DB**	**Outlet Temp.°C WB**	**Time Hours GMT**	**Moisture Content %**
	30	45	36	27	1505	
	30.5	44	31	27	1513	
Residence Time,	30	44.5	30	26	1521	
tr = 48min.	30	44	32	26	1529	
	30.5	45	31	26	1537	
	30.5	45	35	26.5	1545	
	30.5	45	34	26.5	1553	**16.80%**

Moisture content after 4th pass: mc1 = 16.8, mc2 = 16.8, mc3 = 16.4, mc4 = 16.5, mc5 = 17, mc6 = 17.8 16.80%

Σmc = 101.3, therefore Av. Mc is 16.8%

Pass No. FIVE	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp.°C DB	Outlet Temp.°C WB	Time Hours GMT	Moisture Content %
	27	43	41.5	27	08:10	No rice in dryer
	27.5	43	31	26	08:30	
	27.5	43	28.5	25	08:38	
	28	43	31.5	25.5	08:46	
	28	42.5	31	25.5	08:54	
	29	43	33	26	09:02	
	29	43	33	25.5	09:10	
	29	43	33.5	25.5	09:18	**15.40%**

Moisture after 5th pass: mc1 = 16.1, mc2 = 15.9, mc3 = 15.4, mc4 = 15.7, mc5 = 15.4, mc6 = 14.8 15.40%

Σmc = 108.3, therefore Av. Mc is 15.4%

Pass No. SIX	Ambient Temp. °C	Inlet Temp. °C	Outlet Temp.°C DB	Outlet Temp.°C WB	Time Hours GMT	Moisture Content %
	31	45	31	24.4	1056	
Residence Time,	31	45	31	24.4	1104	
tr = 48 min.	31	45	30	25.5	1112	
	31	45.5	32.5	26	1120	
	31.5	46	33	26.5	1128	
	31.5	46	33	26.5	1136	
	32	46	34	27	1144	
	32	46	32	26.5	1152	
	32	46	32	26.5	1200	**14.40%**

Moisture content mc1 = 14.1, mc2 = 14.9, mc3 = 14.3, mc4 = 14.5, mc5 = 14.5, mc6 = 13.9, mc7 = 14.6, Σmc = 100.8, thus Av. Mc is 14.4%

Pass No. SEVEN	Ambient Temp. °C	Inlet Temp. °C Temp. °C	Outlet Temp.°C DB	Outlet Temp.°C WB	Time Hours GMT	Moisture Content %
	33.5	48	32	26	1458	
Residence time,	33.5	49	32	26	1506	
tr = 48 min.	34	49	38	26.5	1514	
	34	49	38	26.5	1522	
	34	49	36	26	1530	
	34	49	35	26	1538	
	34	49	42	27	1546	
	33.5	48	40	24.4	1554	**13.10%**
	33,5	48	38	26	1600	

Moisture content after 7th pass: mc1 = 13.2, mc2 = 13.3, mc3 = 13.3, mc4=12.5, mc5 = 12.8, mc6 = 12.3,
Av.Mc=13.1 mc7 = 14.4, Σmc = 91.8,

Thus av mc = 13.1%

ANALYZED DATA FOR GRAPHING

Time	Ta	Ti	Todb	Towb	mc	RH
0	27.5	42	42	26.5	26.6	30
48	28	42	30	26	22.3	72
96	30	44.6	30.3	27	19.5	76
144	31	45.3	33.4	26.9	17.6	62
192	30.3	45	32.7	26.4	16.8	60
240	28.1	43	27.6	25.6	15.4	85
288	31.4	45.6	32.1	25.9	14.4	60
336	33.8	49	36.5	26.1	13.1	45

ANALYSEDDATA
FOR GRAPHING

Ta	Ti	Todb	Towb	MC	Rho	Rha	tr
27.5	42	42	26.5	26.60%	29.1	76	0
28	42	32	28		73.6	59	8
28	42	32	27		67.7	59	16
28	42	31.5	27		70.4	59	24
28	42	29.5	27		82.3	59	32
28	42	28.5	25		75.2	59	40
28	42	28	25		78.3	59	48
28	42	29	25.5		75.4	59	56
28	42	30	26	22.30%	72.7	59	64
30	44	30	26		72.7	57.7	72
30	44	29	25		72.2	57.7	80
30	45	30	26		72.7	57.7	88

30	45	30	26		72.7	57.7	96
30.5	45	31	26		73.2	58.1	104
30.5	45	31.5	27	19.50%	70.4	58.1	112
31.5	46	32	26.5		64.8	58.8	120
31	46	32	26.5		64.5	58.4	128
31	45	34	27.5		60.5	58.4	136
31	44.5	34.5	27		58.2	58.4	144
31	45	34	27		57.9	58.4	152
31	45	34	27	17.60%	57.9	58.4	160
30	45	36	28.5		56.7	57.7	168
30	44	31	24.5		58.4	57.7	176
30	44.5	30	23.5		57.7	57.7	184
30	44	32	25		56.4	57.7	192
30.5	45	31	24		55.7	58.1	200
30.5	45	31	26.5		51.1	58.1	208
30.5	45	31	26.5	16.80%	55.3	58.1	216
27.5	43	31	26		55.6	52.1	224
27.5	43	31	25		55.6	52.6	232
28	43	31.5	25.5		56	56	240
28	42.5	32	25.5		56	56	248
29	43	32	26		57.2	56.9	256
29	43	32	25.5		54.6	56.9	264
29	43	33.5	25.5	15.40%	54	56.9	272
31	45	33	24.4		55	58.4	280
31	45	33	24.4		55	58.4	288
31	45	33	25.5		55	58.4	296
31	45.5	33	26		55	58.4	304
31.5	46	33	26.5		55	56.1	312
31.5	46	33	26.5		55	56.1	320
32	46	35	27		54	56.4	328
32	46	35	26.5		54	56.4	336
32	46	35	26.5	14.40%	54	56.4	344
33.5	49	36	27		49.9	57.5	352
33.5	48	37	26		49.9	57.5	360
33.5	49	37	26		49.9	57.5	368
34	49	38	26.5		40.2	57.9	376
34	49	38	26.5		40.2	57.9	384
34	49	39	26		38.6	59.9	392
34	49	39	26		38.6	57.9	400
34	49	42	27		30.8	57.9	408
35	48	42	24.4		27.1	57.5	416
35	48	43	26	13.10%	27.1	57.5	424

Ta	tr	Psa	Xa	Todb	Psodb	Xodb
27.5	0	3673.83	0.013597	42	8218.28	0.015036
28	16	3782.86	0.013597	32	4761.16	0.020437
28	32	3782.86	0.013597	29.5	4126.99	0.021573
28	48	3782.86	0.013597	28	3782.86	0.01873
30	64	4247.6	0.015418	30	4247.6	0.019552
30	80	4247.6	0.015418	30	4247.6	0.09552
30.5	96	4371.25	0.015991	31	4498.02	0.020891
31.5	112	4627.97	0.017166	32	4761.16	0.019534
31	128	4498.02	0.016554	34	5327.76	0.020437
31	144	4498.02	0.016554	34	5327.76	0.020437
30	160	4247.6	0.015418	36	5951.86	0.02143
30	176	4247.6	0.015418	30	4247..6	0.015418
30.5	192	4371.25	0.015991	31	4498.02	0.01577
30.5	208	4371.25	0.015991	31	4498.02	0.01577
27.5	224	3673.83	0.012832	31	4498.02	0.01577
28	240	3782.86	0.013279	32	4761.16	0.01681
29	256	4009.38	0.014327	32	4761.16	0.016378
31	272	4498.02	0.016554	33	5037.56	0.017486
31	288	4498.02	0.016554	33	5037.56	0.017486
31.5	304	4627.97	0.016357	33	5037.56	0.017486
32	320	4761.16	0.016933	35	5632.33	0.019205
33.5	336	4761.16	0.016933	35	5632.33	0.019205
34	352	5180.9	0.018841	37	6286.95	0.019873
34	368	5327.76	0.018841	38	6638.23	0.016823
34	384	5327.76	0.020138	39	7006.33	0.017057
34	400	5327.76	0.020138	42	8218.28	0.015936
34	416	5327.76	0.018841	42	8660.48	0.014749

APPENDIX V Field data Collection

Design, Development And Evaluation Of A Continuous Flow-mixing Type Grain Dryer.

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

   (c) 4acres (d) over 5 acres

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

   (b) June (c) July (d) other………..

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

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

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

(a) $2\frac{1}{2}$ months (75 days) (b) 3 months (90 days)

(c) $3\frac{1}{2}$ months (105 to 115 days) (d) 4 months (over 120 days

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

(c) 3 harvests

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

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

6. For the past ten years can you give the quantities you have produced per area?

YEAR	SIZE OF AREA(acres)	QUANTITY(bags)
2009	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2008	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2007	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2006	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2005	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2004	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2003	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2002	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2001	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8
2000	2; 3; 4; 5; 6; 7	3; 4; 5; 6; 7; 8

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

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

   © land to do the farming (d) labour requirements

8. Do you use a dryer? (a) Yes (b) No

8a. If no, how then do you dry your paddy rice? (a) Sun drying (b) Shade drying.

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

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

11. Can you alone afford a dryer of about GHc 33,000.00? (a) Yes (b) No

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

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

    (a) Yes (b) No

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

15. How would a dryer enhance your production capacity?

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

16. If you get a dryer and it increases your annual production, will you have market for your produce? (a) Yes (b) No

17. How do you do your harvesting? (a) manual labour (b) combine harvester (c)mini-combine harvester (d) any other means

18. How do you do cleaning of the paddy? (a) manually blowing air

    (b) Using engine spraying machine (c) using any other machine

19. Is irrigation available to you? (a) Yes (b) No

20. If you are able to dry immediately after harvesting? (Immediately here means the paddy

Must be dried within 8 to 24 hours for quality grain) (a) Yes (b) No

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

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

    © Diesel (d) vegetable waste (rice husks)

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

24. Are you ready to grow a particular type of rice variety with other growers if requested by rice buyers?

(a) Yes (b) No

Do you have any other thing to say about dryer? This dryer can be used for drying corn also. Do you intend to use it for both grains