DEVELOPMENT AND PERFORMANCE STUDY OF A CABINET DRYER

A THESIS
BY

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MD. IMTEAJ ZUBAIR
Student ID: 1105030
Session: 2011-12
Semester: January – June, 2012

MASTER OF SCIENCE (MS)
IN
FOOD ENGINEERING AND TECHNOLOGY

DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY
UNIVERSITY, DINAJPUR

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DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

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JUNE, 2012

DEDICATED TO
MY
BELOVED PARENTS

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The author
June, 2012

ABSTRACT

Moisture content is an important factor in the preservation of grains. If the moisture content is above the safe moisture level at suitable temperature, the grains are in the risk to be attacked by different types of insects and microorganisms and loss of value due to spoilage. Due to the lacking of drying facilities, a huge amount of produced grains are lost every year in Bangladesh particularly in the rainy season. Keeping the problem in mind a cabinet dryer was developed in the Power and Machinery Laboratory, Faculty of Agro-Industrial and Food Process Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur. The dimensions of the dryer are 1.52m long, 0.61m wide and 1.52m high. An automatic temperature control system was incorporated in the existing dryer by using thermocouple, temperature controller and magnetic contractor to control the quality of the grain. This system maintains the safe drying temperature level for grain. There are four trays placed one over other inside the dryer. The grain holding capacity of each tray is 10kg of fresh paddy. About 40kg paddy was dried per batch at the temperature 43-44^{0}C in seven hours period from the initial moisture content of 25.2% to final moisture content of 13.6% (wb). The electricity cost for drying per kilogram of paddy was Taka 3.74.

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INTRODUCTION

CHAPTER I

INTRODUCTION

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 minimize 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 safe moisture content by the application of heat. Drying is practiced 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).

The post-harvest losses in Bangladesh from producer to retailer were 10.74% for Aman 11.71% for Boro, and 11.59% for Aus. The estimated total post-harvest losses of rice at farm level in Bangladesh were 9.16%, 10.10% and 10.17% for Aman, Boro and Aus respectively. Total post-harvest losses of rice at farm level are 85.28 – 87.77 % of the total post-harvest losses and the storage loss is 33.92 – 40.99 % of total losses at farm level. The storage loss of rice is (3.45 – 4.14%) and it is followed by drying (2.19-2.37 %), harvesting (1.60-1.91%), threshing (1.10-1.79%) and transportation (0.87-1.13%). The estimated total post-harvest losses of rice at processor level in Bangladesh were 1.30%, 1.30% and 1.13% for Aman, Boro and Aus respectively while the estimated total post-harvest losses of rice at wholesale level were 0.17%, 0.18% and 0.19% for Aman, Boro and Aus respectively and at retail level were 0.27%, 0.31% and 0.28% for Aman, Boro and Aus respectively. (Bala *et al.*, 2010)

Annual loss of grain from harvesting to consumption is estimated to be 10-25%. The magnitude of these losses varies from country to country. These losses are significantly high in the developing countries because of favorable climates which cause deterioration of stored grains and also because of lack of knowledge and proper facilities for drying and storage. Great effort is being made to increase crop production, but little or no effort is being made to improve drying and storage facilities especially in developing countries (Bala, 1997).

A grain dryer, as its name would suggest, is a machine manufactured simply to dry grain. The grain dryer is an expensive equipment and not one many farmers have. Rather, they may use the services of farming cooperative or rent one in some situations.

In Bangladesh, farmers mainly depend on the sun drying method to remove moisture from the grain after threshing. Early threshed grain contains a high moisture content which rapidly spoils. To avoid this losses farmer sometimes thresh grain after the rainy day this may deteriorate the quality also. In the present situation dryer is usually used in automatic rice mill for milling purpose and most of the dryers are imported from abroad. The price of these dryers is so high for a farmer at rural level to purchase this individually. So this is the primary requirement to develop a low cost dryer to reduce the loss of grain during the rainy season.

Rough rice drying in non-industrialized countries like Bangladesh is commonly achieved by spreading it on beaten earth or mats directly exposed to solar radiation. Multiple cropping in the tropics with improved rice varieties forces some harvesting to be done during the wet rainy season when sun drying is not possible. Using the sun drying, there is no guarantee on the final quality of dried rice. This method is slow and susceptible to rainfall, birds, insects, dust and other contamination. Spoilage may also result from occasional rains. Considerable losses, from 10% to 25% can often occur (Excell, 1980). Accurate scheduling of farm operations and efficient use of land, labor, machinery, and other resources cannot be coordinated well with the sun drying method due to weather uncertainty. The natural sun drying of a high moisture paddy requires little capital cost, but there is a high labor cost in keeping the grain turned regularly and protecting it from wet weather. Even then, kernel checking and breaking is a serious setback. This unfavorable climate condition dictates the need for a more effective method of drying grain.

Not only paddy, other cereals and grains with high moisture content are also not safe for long time storage. During rainy season sometimes it rains cats and dogs for the whole week. Farmers with their harvested grains are in serious trouble to thresh and store. Not only in rainy season even in winter season sometimes foggy weather without sunlight for few days causes the same problems in crops drying. Therefore, a mechanical drier is essential for rural use in small scale which will be cheap, easy to operate and available locally or can be manufactured with available local materials.

A control system is a device, or set of devices to manage, command, direct or regulate the behavior of other device(s) or system(s). Temperature control system is now widely used in modern grain dryer having the following advantages:

i. Reduce the use of the energy.

ii. Maintain the safe temperature level of grain drying which is safe for the grain or seed quality and reduce the breakage output during milling.

iii. Simple to size and select.

iv. Many options are available, such as different capillary lengths and temperature ranges.

Temperature control is one of the most important factors in drying grain both in case of grain processing and for milling purpose. Therefore, incorporation of an automatic temperature control system in a dryer is an essential part of dryer development and modification. Automatic feedback control of temperature in a dryer not only reduces energy loss, it also ensures quality drying of the products.

Therefore, in this research work development and improvement of a cabinet dryer is being performed together with an effort to incorporate an automatic feedback temperature control mechanism.

Therefore, the specific objectives of the research work are

i. To design and fabrication of an electric power operated cabinet dryer incorporating temperature control system.

ii. To evaluate the performance of the dryer for drying of paddy.

CHAPTER II

LITERATURE REVIEW

CHAPER II

LITERATURE REVIEW

2.1 Review of drying

2.1.1Introduction

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 tripled, the technology of drying has not caught up (De Padua 1979). Most farmers in developing countries dry their paddy rice in the sun. 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).

2.1.2 Principle of Drying

Drying is the process of moisture removal from the product, or grain in this case. Since grain is a hygroscopic material which can either absorb or desorbs moisture from the air or its surroundings depending on the difference in vapor pressure, moisture transferred from a higher vapor pressure, to the lower one. In the sun drying process, grain is heated by solar radiation thus creating a higher vapor pressure in grain than the surrounding air. In the same manner, the heated air drying process starts when the grain is heated (by conduction) when it comes in contact with the air. Higher velocity air flow in heated air drying has the advantage of reducing the boundary layer of the grain, thereby increasing the heat transfer coefficient of the grain, as well as increasing the rate of moisture movement from grain to the surrounding air. Therefore, the drying rate of a specific kind of grain is dependent on both air temperature and air flow rate (http://www.fao.org/docrep/X5036/x5036E0x.htm).

2.1.3 Chemistry of drying

During drying, it is necessary to remove free moisture from the surface and also from the interior of the material. When hot air is blown over the grain, heat is transferred to its surface and the latent heat of vaporization causes water to evaporate. Water vapor diffuses through a boundary film of air. This creates a region of lower vapor pressure at the surface of the grain and a water vapor gradient is established from the most interior part of the grain to the dry air (Robert, 1979).

The gradient provides the driving force for removal of water from the food. Water moves to the surface by the following mechanisms:

- Liquid movement by capillary force.
- Diffusion of liquids caused by difference in the concentration of solutes in different regions of the grain.
- Diffused liquids absorbed in a layer at the surface of solid components of the grains. (Stephen *et al.*, 2009)

Water vapor diffusion in air spaces within the grains is caused by pressure gradient. Difference in temperature is however responsible for the created pressure gradient, thus in defining the properties of air required for drying.

Second phase or constant rate period

During this period, drying takes place at the surface of the grain and is similar to evaporation of moisture from free water surface. The rate of evaporation depends largely on the surroundings and only little on the type of grain. The period ends when the moisture content is below that necessary to replenish the moisture of the surface that is at the critical moisture content (Fig.1).The three characteristics of air that are necessary for successful drying in the constant rate period are (Brooker*et al.,* 1973):

- A moderately high dry bulb temperature.
- A low relative humidity.
- A high air velocity.

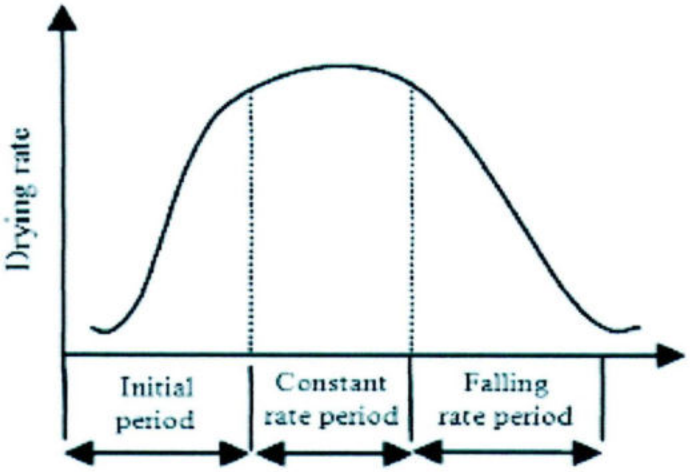

Fig. 2.1: The drying curve

Third phase or falling rate period

It is the phase during which migration of moisture from inner interstices of each particle to the outer surface becomes the limiting factor that reduces the drying rate.

Since grains belong to the class of hygroscopic food (materials that contain bound water) they have two falling rate periods namely; first falling rate periods and second falling rate period:

- **First falling rate period:** It represents a condition whereby the grain surface is no longer capable of supplying sufficient moisture to saturate the air in contact. It is under the condition that the rate of drying depends very much on the mechanism by which the moisture from the grain is transferred to the surface. At the conclusion of this falling rate period, it may be assumed that the surface is dry.
- **Second falling rate period:** At this stage the vapor reaches the surface by molecular diffusion. The forces controlling the vapor diffusion will determine the final rate of drying and this will be largely independent of the conditions outside the material.

Thus in drying grains, two processes are involved:

- The transfer of heat to evaporate the water contained in the grain.
- The transfer of mass as internal moisture and evaporated liquid. The internal mechanisms which control moisture are diffusion, capillary action, shrinkage, vapor pressure, gravity and vaporization.

The rate of drying depends on the proportion of air (dry bulb temperature, wet bulb temperature and relative humidity), the velocity of air, surface heat transfer coefficient and the properties of food being dried.

To determine the time required to achieve the desired reduction in product moisture content, the rate of moisture removed from the product must be determined (Brooker*et al.,* 1973).

2.1.4 Factors affecting drying rate

The factors that affect drying rate are:

- Relative humidity of air.
- Time of drying.
- Method of heat supply.
- Grain depth.
- Feed rate.
- Temperature of inlet and outlet air.
- Drying operation.
- Moisture content of grain (Brooker*et al.,* 1973).

A temperature of 43° C is recommended for drying the paddy for seeds and this can be achieved with shade drying, (IRRI, 2007a). Higher temperatures can lead to physicochemical disorders in the grain. Wherever possible, it is worthy to harvest most grain crops during a dry season and simple drying methods such as sun drying are adequate. However, majority of the paddy harvest does not coincide with a suitably dry period; rather it falls in rainy season in the country like Indonesia where the irrigated paddy field is limited. Natural methods of drying make exposure of the wet grain to the sun and wind. Artificial dryers employ the application of heat from combustion of fossil fuels and biomass resources, directly or indirectly, and in both natural and forced convection airflow systems, (Muehlbauer and Cheigh, 1983).

In order to maintain the quality of harvested paddy, mechanical dryers are needed, especially in the rainy season when sun drying is often not possible, (Hien, 2005). However, some conventional mechanical dryers with kerosene burners as heat source, those were in use in the region in past, need around 10–15 liters of kerosene for each ton of paddy, (Gummert, 2007). These greenhouse gas emissive dryers are in questions from the environmental aspects. Further, prices for kerosene are steadily increasing. Cheaper alternatives can be used, such as rice husk. Rice husk, a byproduct of the rice milling process, is available in abundance, is low in cost, and can be used in specially designed furnaces. Using rice husk is also more environment friendly than kerosene because, when burnt, it emits only carbon that was accumulated by the rice plant from the environment into the atmosphere and thus does not increase the atmospheric carbon dioxide balance (Gummert, 2007).

Braga *etal.*, (2001) developed and tested a batch drier for agricultural products. The system consisted of an adequately sized tank, 2 fans and 2 firewood heated generators to accommodate the appliance. Primary air combustion was supplied by a small fan. The performance of the drier was tested in drying groundnuts (Leguminosae-faboideae). They reported that it was simple, low-cost and could be easily constructed by farmers.

A batch drier is commonly used in northern Iran (Mazandaran). The moisture content distribution across a batch drier was investigated and reported by TabatabaeefarandRafiei (2002). The inside dimensions of the drier bins were 7 m long, 2 m wide and 0.8 m in depth. The inside of the bin was divided into 16 cells with 4 regions apart from the burner and 4 depths. Nine drying periods were employed. The rough rice was placed inside the bin, dried (in nine different drying periods) and was taken from all the 16 cells with a hand operated sampler. It was found that the three factors in the design were period, region and depth. Three similar bins were again tested for comparison. A new Duncan multiple, range test of analysis of means was applied for the regions, depths and cell. Results showed that variation in moisture distribution was significant, indicating that warm air was not distributed uniformly. At the end of the drying period, average moisture content in 4 depths, from top to bottom, and at the four regions was 6.67% with a 0.21% of standard deviation.

In a study in Thailand, the performance of a modified batch drier was compared to that of a conventional unit. Some 2000 kg of fresh longan were used in each drying batch. The depth of fresh longan was 60 cm, the drying air temperature 75-80^{O}C and the airflow rate 3.8 m^3/second (air velocity 0.7 m/second). Test results indicated that the modified drier was more convenient to work with and required less turning time for longan inside drier. The quality of the dried longan was uniform and did not differ from those dried in the conventional drier. (Phaphuangwittayakul*etal.*, 2004).

Oberoi*etal.,* (2005) reported that freshly harvested red chilli (Capsicum annuum cv. CH-3) was subjected to conventional sun-drying (CSD) and drying in the batch-type drier (BTD) using indirect hot air. The 2 drying methods were compared with respect to temperature, time combination and quality parameters, including physico-chemical and microbial attributes. It took 25 h to lower down the moisture content of chillies from 361 to 10.1% (db) in the BTD compared to the CSD, which took 10 days to bring down the moisture content to 9.9% (db). The colour retention was significantly better in the chillies dried using BTD compared to CSD. There was no difference in the oleoresin content but capsaicin content was lower in chillies dried under hot sun.

Madhiyanon&Soponronnarit (2005) described, paddy drying conducted in a two-dimensional spouted bed batch drier to investigate the effects of downcomer airflow, drying temperature, and initial moisture content on drying kinetics, milling quality, and thermal energy consumption. The system of spouted bed dries and a comparison of spouted bed drying in the study, and fluidized bed drying in the related literature, were also discussed. Downcomer air flows of 0, 20, and 30%, inlet air temperatures of 110, 130, and 150^0C, and initial moisture contents of 18-35% (db) were used. It was reported that moisture transfer did not only occur in the spout region but also took place in the downcomer region. The moisture content and temperature of the paddy dropped as grain moved downward in the downcomer, which resulted from the presence of an evaporative cooling phenomenon. The characterization of drying curves regardless of any drying condition could be described by nearly linear relationships between moisture content and time. Although high downcomer air flow and drying temperature could enhance effective moisture reduction, they caused an adverse decrease in critical moisture content and HRY (head rice yield). Critical moisture content and HRY could also increase with an increase in initial moisture content. The difference in moisture content between the initial and critical moisture contents varied between 4.5 and 8.0% (db), depending upon drying conditions. No significant effect on color was evident. From the point of view of HRY, the correct management of a two-stage spouted bed drying system could be a suitable and attractive alternative for rice mills. Finally, a comparison between the spouted bed drying and fluidized bed drying showed that the spouted bed had advantages over the fluidized bed in terms of product quality. The specific drying rates (kg water evaporated h^{-1} m^{-3}) of both techniques were comparable. With respect to energy consumption, spouted bed drying was not as efficient as fluidized bed drying for intermediate initial moisture content, but a contrary result was obtained for low initial moisture content.

DescoteauxandSavoie (2006) described, a pilot scale batch drier built with a capacity of six mid-size bales (0.81x0.89x2.44 m per bale) on one layer or 12 bales on two layers. With a floor area of 2.44x4.88 m, the pilot scale drier included a 102-kW propane burner and a 12-kW blower located at the end of the air duct system, thereby creating a negative air pressure. The side walls were made of plastic film which adhered to the bales because of suction. A re-circulation duct returned a variable fraction of the exhaust air to the input to improve thermal efficiency depending on the level of vapor saturation. Part of the dryer's originality lied in its bi-directionality, i.e. heated air could flow alternately from the top plenum downward or from the bottom plenum upward. Bi-directional airflow was automated by two pairs of gate valves installed in two incoming air ducts and two outgoing air ducts. Results showed that one-layer batches reached an average moisture content of 12% in less than 5, 9, and 14 h with initial moisture contents of 21%, 24%, or 34%, respectively. Two-layer batches reached an average moisture content of 12% in less than 10 and 24 h with initial moisture contents of 21% and 30%, respectively. Total energy efficiency based on combustion heat and electrical energy for water evaporation ranged from 29% to 49% with an average of 38% in the first half of drying time and from 6% to 31% with an average of 17% in the second half of drying time. The difference between moisture content in the upper half and the lower half of bales was reduced with increased airflow inversion cycles. Because of lateral variation in final moisture content due in part to non-uniform initial moisture and bale density, some over-drying would be required to ensure that all bales are dried to a safe storage moisture level.

Inoue *et al.,* (2006) described, soybeans (*Cvtsurumusume*) dried using a recirculating batch drier, which was used for the drying of all kinds of grains including rice, wheat, and soyabean seeds. The rate of seed coat cracking and mechanically broken soyabean seeds during the drying process under the automatic temperature control increased when the moisture content of the grain decreased to 17% (wb) and finally exceeded 4% at moisture contents below 15% (wb) For the next experiment, the temperature of the air flow was controlled manually so as to prevent seed coat cracking from the test of thin layers. The temperature was calculated from an equation of the maximum distortion of seed coat and the approximated distortion of the seed coat using the average moisture content of the seeds and the moisture content of the seed coats in equilibrium with the ambient air conditions. In this case, there was no increase in seed coat-cracked soyabean seeds; however, the rate of mechanically broken soyabean seeds increased to more than 3% at moisture contents below 17% (wb), which was a significantly higher rate than with drying by unheated air ventilation. This was due to the combined effects of heat distortion in the process of drying and impaction in the transport process involving screw conveyors and bucket conveyors just after the process of drying.

Bockelmann*et al.,*(2005) reported the possibilities of optimizing the process combination of warm-air drying and microwave tested for grain maize. The combination of these two techniques makes the water-permeable outer layers and shells to remain more capable of diffusion until the end of the drying process. For the realization of the tests, a batch drier was designed instead of a continuous-flow drying system. The design of the experimental drying system as well as the techniques and methods were given. Two batch mixer trials (convection and microwave-convection) were carried out with freshly harvested moist maize. Pure convection drying from an initial moisture content of 29% to a target moisture content of 14% required a drying time of 210 minutes. Thermal energy consumption was 1.98 kWh per kg of extracted water. Under comparable process-air conditions in the trial with microwave support, the extraction of the same quantity of moisture required a drying time of 135 minutes and the specific energy demand also significantly decreased to 1.25 kWh per kg of water.

Rostami*et al.,* (2006) studied the effect of drying in four different type of driers (batch wagon drier, continuous vertical drier, batch cylindrical vertical drier and continuous cylindrical vertical drier) with two levels of moisture content in pistachio nuts (4-6 and 10-12% (db) on fuel consumption, and change in splitting, drying uniformity, damage, storage life, texture, flavour, rancidity and colour of pistachio kernel, were studied and compared to solar drying. It was found that drying up to moisture content of 4-6% in continuous vertical drier had the most negative effect on splitting of pistachio nuts. Splitting number decreased in this drier. Solar drying increased nut splitting and the maximum damage rate was recorded in wagon drier. Results indicated that solar drying had maximum uniformity and that the cylindrical vertical drier could not dry pistachio nuts uniformly, because pistachio nuts had no movement in this drier.

2.2 Review of auto temperature control system

Control system engineering is well established. The application of automatic control to any new system or process normally involves the solution of problems introduced by special requirements. Although the basic control principles are the same, measurement of the controlled variable and reaction times are frequently different.Recently, automatic temperature control system is rapidly gaining popularity.

This automatic temperature control system is designed which is supposed to keep the temperature inside the dryer chamber within required range.

Measurement and control of temperature is one of the most common requirements of industrial instrumentation and the thermocouple is by far the most widely used temperature sensor. Its characteristics include good inherent accuracy, suitability over a broad temperature range, fast thermal response, ruggedness, high reliability and low cost.

In grain drying, automatic control systems have becomecommonplace. Moreira and Bakker-Arkema (1992) haveprovided an overview of modern dryer control systems. The best systems use conventional adaptive control, with feedforwardand feedback. These systems require a mathematical description of the process and the ability to sense the process variable (i.e., grain moisture) on-line. However, unlike grain drying where product moisture is the process variable, the success of roasting is not defined by a single variable.

Forbes *et al.,* (1984) showed that model based controllers performed better than conventional feedback and feed forward ones in the case of corn dryers. Ravi *et. al.,* (1986) described the system by a state space model. They designed a time varying optimal control law and checked the performance of the designed controller by closed loop simulation.

Eltigani*et al.,* (1987) used feedback and feed forward control configurations based on an empirical parameter adaptive equation and developed a reliable material moisture content controller that avoid long dead-times and frequent and large load upsets. Li and Biegler (1988) extended non-linear internal model control (NLIMC) to processes with constraints on inputs as well as outputs of the process formulated a successive quadratic programming problem. The method needs a perfect model of the plant.

Zhang and Litchfield (1991) created a fuzzy logic control system for a corn dryer that maintains physical quality and at the same time regulates final moisture. A fuzzy control system for drying soybeans, where seed coat cracking, seed viability, and moisture content were all considered, was developed byDavidson et al. (1996). A fuzzy logic controller using sensor inputs and linguistic observations from the operator was used by Davidson et al. (1999) to control a hot-air peanut roasting process.

CHAPTER III

MATERIALS AND METHODS

বিজ্ঞান ও প্রযুক্তি বিশ্ববিদ্যালয়
দিনাজপুর

CHAPTER III

MATERIALS AND METHODS

3.1 Theoretical considerations in designing a cabinet dryer

The basic principle of grain drying is that natural air or hot air has to be passed through a chamber or cabinet where the wet grains will be kept on trays. The air or hot air will remove moisture from the grain and reduce the moisture content of the grain. To do this, air has to be blown using a blower, a heater or heat exchanger will be required to heat the air, a common duct to carry the hot air, narrow ducts or pipes to distribute the air to respective chambers and suitable outlet lines to let the moist air exit. Thermometers are needed to set to the drying chambers to measure the inside drying air temperatures. Systems are needed to establish the control of the amount of air flow and also to control the hot air temperatures. Insulation of the heating surface is required to reduce the loss of heat to the atmosphere. A stirring system is needed to stir the grain at certain interval for proper drying.

In this research work, a small scale batch type cabinet grain dryer has been designed and developed on the basis of the above basic theories using locally available materials. The dryer size has been designed on the basis of drying 40kg of paddy at a time.

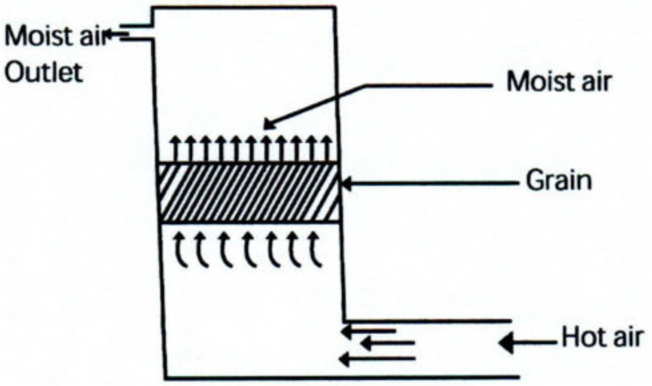

Fig. 3.1: Basic principle of grain drying

3.2 Design and construction of different parts of the dryer

3.2.1 The drying chamber

A structure was made using 1.5 inch × 1.5 inch (3.81cm × 3.81cm) angle bar. It was shaded with plane M.S. sheet to give a total size of the dryer to be 1.52m high, 1.06m long and 0.61m wide. Insides of the chambers were covered with 1/2" (1.27cm) thick cork sheet to reduce heat loss towards outside. There were two cabinets or chambers in the dryer respectively the upper chamber and the lower chamber. Two rails were made using angle bar to support the trays with grain. Inside each chamber two 2" (5.08cm) pipe ran from one side to other with 1.2cm holes made around the pipe which carries hot air to the chamber from the outside 3" (7.62cm) duct. Baffles were used to ensure proper distribution of air inside the chamber.

3.2.2. Measurement of heater power by clip-on meter

To measure the power of the heater, at first we measured the amount of voltage and current flow through the heaters by Clip-on meter. Then power was measured by the following equation:

$$P=VI$$

Where,

P=Power of the heater in Watt
V=Voltage of the heater in Volt
I=Amount of current flow in Amp.

3.2.3. Hot air supply system

A structure was made using angle bar to support a blower of 420 watt, two insulated electric heaters of respectively 1400 watt and 1600 watt, and organize other accessories. The regulator could be adjusted to increase or decrease the amount of air flow. Two insulated electric heaters were placed inside a thermally insulated chamber one side of which was connected to the blower and the other side to the hot air conveying duct. The out side of the heater chamber was covered with earth work to reduce the heat loss. The main duct or pipe (GI pipe) for conveying hot air was a 3 inch pipe which was connected to the outlet pipe (GI pipe) of the heating chamber. The pipe was connected using an elbow with a vertical same size pipe of length 1.22m. From this vertical pipe four openings were made and connected with suitable connectors to the 2 inch pipes of the dryer cabinets. The 3 inch main duct was insulated by using cork sheet of 2 mm thickness to reduce heat loss to the atmosphere.

3.2.4 Moist air outlet

The hot air supplied to the dryer from the duct should have suitable passage to the exit from the drying chamber to enhance drying. For this reason a 1"dia pipe outlet was connected to upper portion of the opposite side of the air entrance of the dryer. Due to the smaller size diameter of the exit pipe compared to the inlet pipe, it permitted opportunity for the air to absorb moisture from the grain under drying.

3.2.5 Measurement of drying air temperature

To measure the temperature of the air, inside the dryer, two thermometers were set on the wall of the dryer. The thermometers were of stainless steel made in China and capable of measuring temperature up to 150^0C with a resolution of 2^0C. A metallic temperature sensitive rod senses the temperature of the inside air of the drying chamber and the dial indicator on the temperature gauge shows the temperature.

3.2.6 Trays for holding grains

Four trays were made of steel sheet of thickness 20 gauge. The size of each tray was 0.92m long and 0.53m wide. The trays were able to hold 10kg wet grain (paddy) at a time. Small holes were made of 2mm size at the bottom side of the trays to permit air flow through grains. The tray had suitable handles for loading and unloading purposes.

3.3 Materials used for temperature control system

An auto temperature control system was established in this dryer to control safe temperature for grain drying. For this a thermocouple, a temperature controller (xmtd-1000) and a magnetic controller (DMC 12a) were inter connected with the heater switch and the dryer chamber.

3.3.1 Temperature controller

A temperature controller is an instrument used to control temperature. The temperature controller takes an input from a temperature sensor and has an output that is connected to a control element such as a heater or fan.

To accurately control process temperature without extensive operator involvement, a temperature control system relies upon a controller, which accepts a temperature sensor such as a thermocouple as input. It compares the actual temperature to the desired control temperature, or setpoint, and provides an output to a control element. The controller is one part of the entire control system, and the whole system should be analyzed in selecting the proper controller. The following items should be considered when selecting a controller:

1. Type of input sensor (thermocouple, RTD) and temperature range
2. Type of output required (electromechanical relay, SSR, analog output)
3. Control algorithm needed (on/off, proportional, PID)
4. Number and type of outputs (heat, cool, alarm, limit)

There are three basic types of controllers: on-off, proportional and PID. Depending upon the system to be controlled, the operator will be able to use one type or another to control the process.

An on-off controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses the setpoint. For heating control, the output is on when the temperature is below the setpoint, and off above setpoint. Since the temperature crosses the setpoint to change the output state, the process temperature will be cycling continually, going from below setpoint to above, and back below. In cases where this cycling occurs rapidly, and to prevent damage to contactors and valves, an on-off differential, or "hysteresis," is added to the controller operations. This differential requires that the temperature exceed setpoint by a certain amount before the output will turn off or on again. On-off differential prevents the output from "chattering" or making fast, continual switches if the cycling above and below the setpoint occurs very rapidly. On-off control is usually used where a precise control is not necessary, in systems which cannot handle having the energy turned on and off frequently, where the mass of the system is so great that temperatures change extremely slowly, or for a temperature alarm. One special type of on-off control used for alarm is a limit controller. This controller uses a latching relay, which must be manually reset, and is used to shut down a process when a certain temperature is reached.

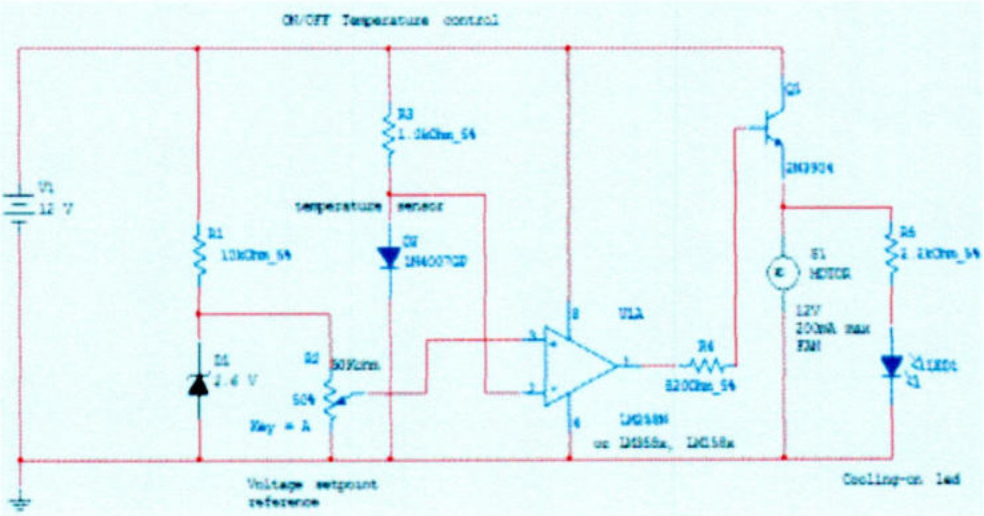

Fig. 3.2: Circuit diagram of a temperature controller

3.3.2 Magnetic contractor

Magnetic contactors are a form of electrical relay found on most electrically powered motors. They act as a go-between for direct power sources, and high-load electrical motors in order to homogenize or balance out changes in electrical frequency which may come from a power supply as well as to act as a safeguard. It should be noted that though they are similar in design, magnetic contactors are not circuit breakers. They do not sever the connection between appliance, and power source during a short circuit. They are detachable from a motor so that an operator may work with that motor; disassemble or maintain it, without the possibility of live current still passing through the device.

Magnetic contactors enable machines in heavy industries to be automatically shut down and started.

When electricity flows through the magnetic contactor, it causes the electromagnet to generate a strong magnetic field. This field pulls the iron core into the coil, and creates an electrical arc. Electricity passes in through one contact and into the contactor's parent device in this manner. To deactivate, the contactor can be physically pulled from the parent device. Also, in the absence of electrical current, the spring pushes the core away from the coil, breaking the connection.

3.4 Incorporation of temperature control system

At first the sensor of thermocouple was set inside the drying chamber to detect the temperature of hot air. The other side of the thermocouple was connected to the controller. The temperature of the hot air was shown at the display of controller. The controller has a system by which the required temperature can setup. Then two connections were done between the controller and magnetic contractor; and the contractor and the heater switch. When the controller showed the hot air temperature below the set point, the contractor kept the switch on of the heaters. But, when the temperature reached at the desire point, the contractor switched off the heater.

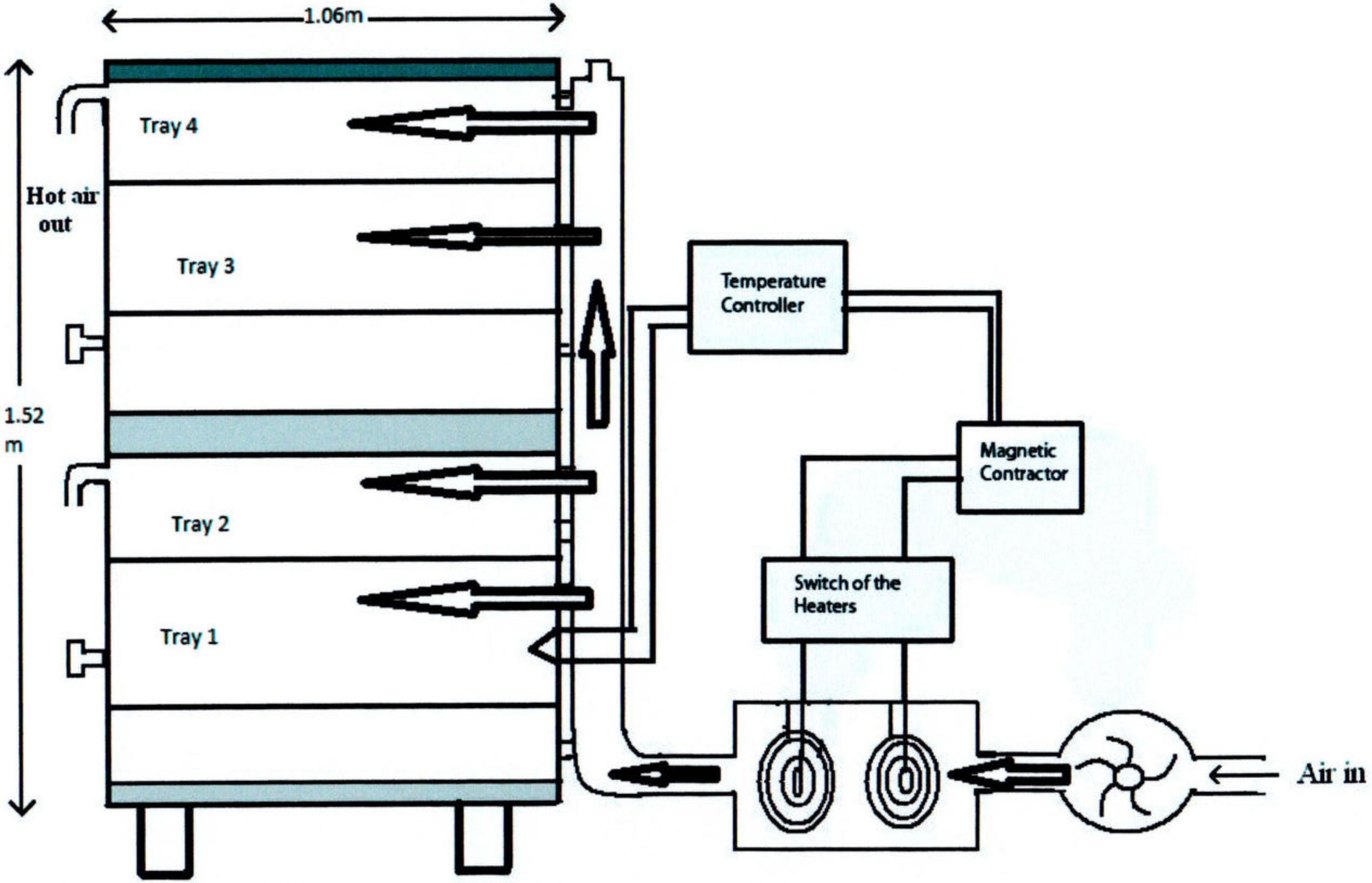

Fig. 3.3: Schematic view of the dryer

3.5 Circuit diagram of the control system:

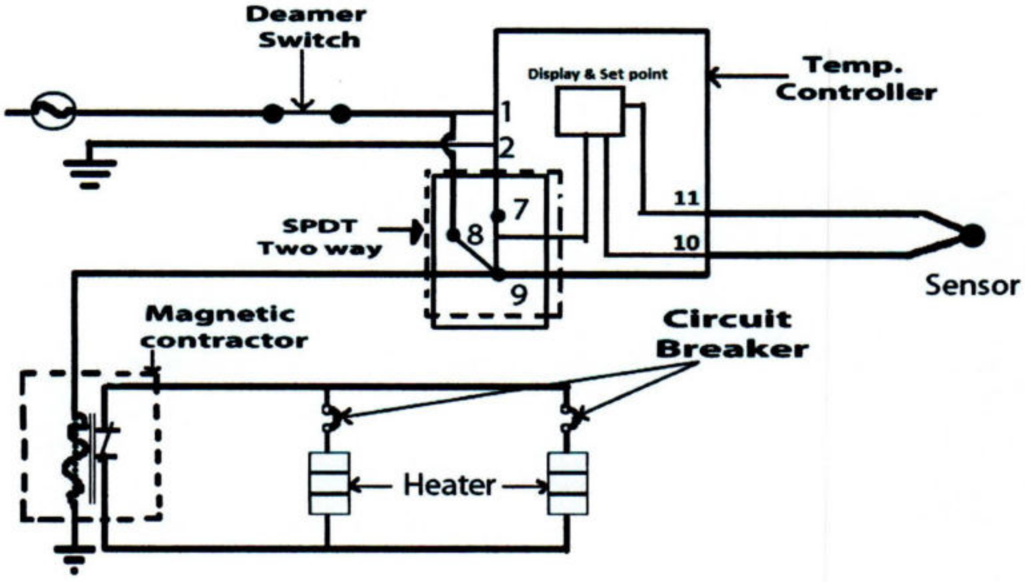

Fig. 3.4: Circuit diagram of the auto-control system when heaters on

From this Fig.3.3 we can see that when the dimmer switch is on, the whole control system start to work. The sensor takes the temperature of the dryer and sends it to the controller. The controller compares the temperature with the set temperature. When the temperature of the dryer is less than the set point, the controller send it to the magnetic contractor by a two way switch (8-9) present in the controller. After receiving, the magnetic cores of the contractor allow current to flow through heaters which means the electrical heaters are switched on. But if the temperature of the dryer shows the equal of the set point, that two way switch changes the direction (7-9) and send it the contractor. Then the cores of the contractor shut the flow of current and the switched off the heaters (Fig.3.4).

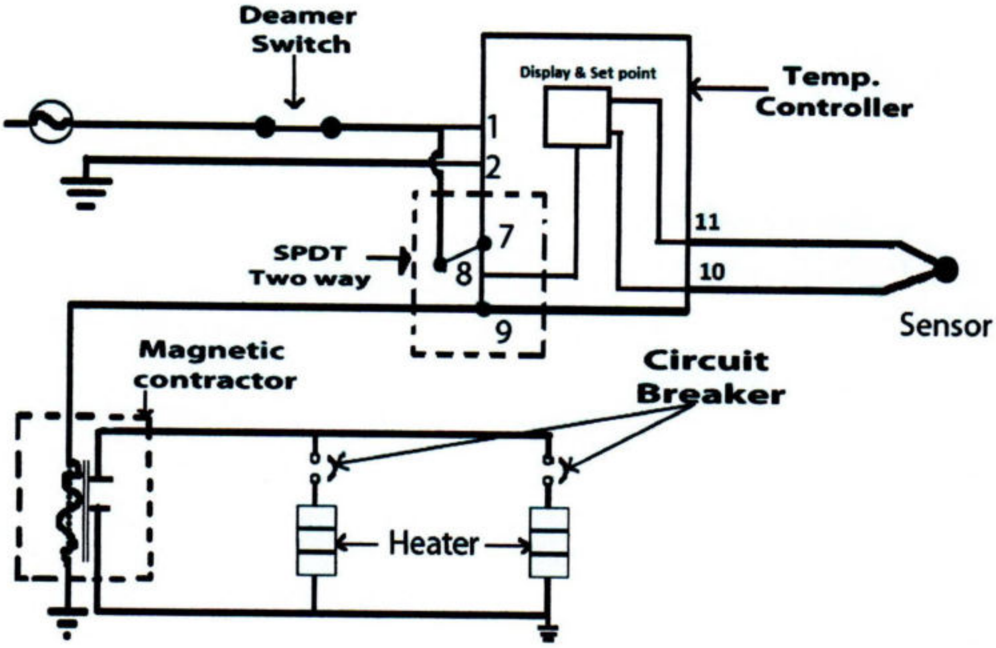

Fig. 3.5: Circuit diagram of the auto-control system when heaters off

3.6 Performance of the dryer

3.6.1 Calibration of temperature

To measure the performance of this dryer, a calibration was done because of the temperature difference between the thermometer in the dryer chamber and the thermocouple used for temperature controller. It occurred due to their separate position in the dryer chamber, or sensor size of thermocouple is small which may not detect the hot air temperature immediately in comparison to the thermometer sensor which is very large.

3.6.2 Measurement of moisture content

To study the drying performance of the dryer, freshly harvested, threshed and cleaned paddy was used for drying. Ten kilograms of paddy was put in each of the four trays uniformly. Moisture content of the grain was recorded at the beginning using a moisture meter (grain moisture meter). From the calibrated chart the temperature controller was set at 29^0C that means the drying temperature is 44^0C, which is safe temperature for paddy drying. The blower and the auto-control system were switched on as described above. Moisture content was recorded at 60 minutes interval. To measure the moisture content at certain time, grain sample was collected from each tray from four different places for uniform results and used the moisture meter to measure the moisture content. The grain was stirred with a stirrer for uniform drying. The thickness of the paddy bed drying was 1 inch and the ambient temperature was 22^0C.

Fig. 3.6: Digital grain moisture meter

To measure the moisture content of a grain sample, a moisture meter (grain moisture meter) was used. The sample was smashed using the provided tool, placed in the chamber and digital reading recorded for each sample including husk. The moisture meter was already calibrated for seven different crops e.g. paddy, rice, corn, wheat etc. in this experiment moisture content for paddy was used.

Initial moisture content of the grain was also determined by oven drying method using an oven dryer. In oven drying method the paddy was dried at 105^0C for 16 hrs. To measure the initial moisture content of the paddy, sample was collected from each tray. The moisture content of the paddy was determined by the following equation:

$$\% \text{ of moisture content (wb)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where,

W_1= Weight of the Petri-dish

W_2= Weight of the sample with Petri-dish

W_3= Weight of the dry sample with Petri-dish

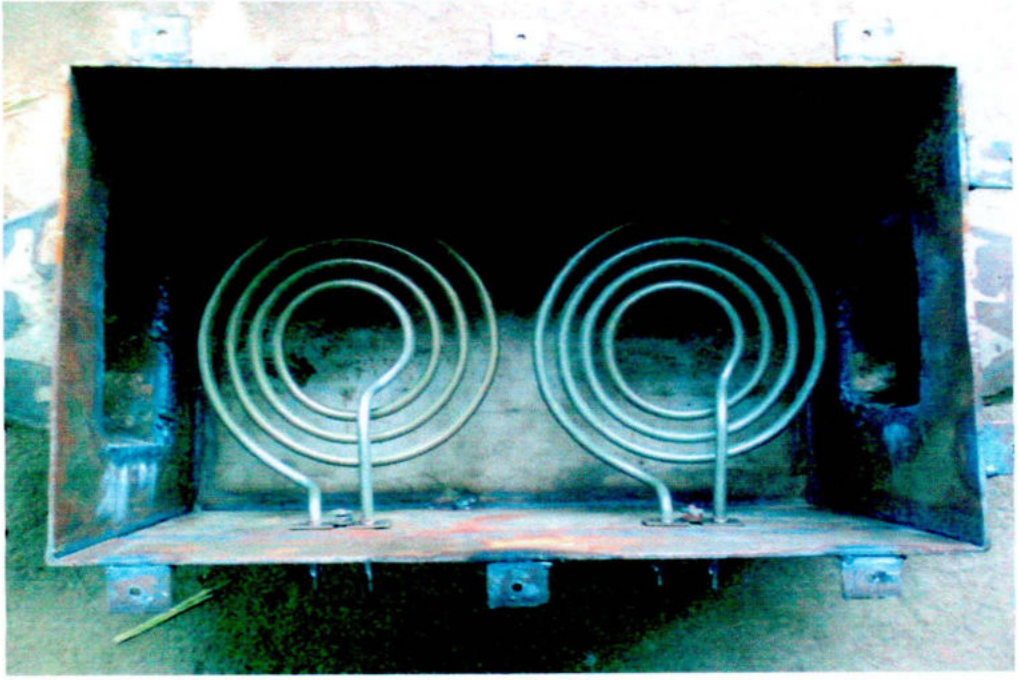

Fig. 3.7: Electrical heaters inside the chamber

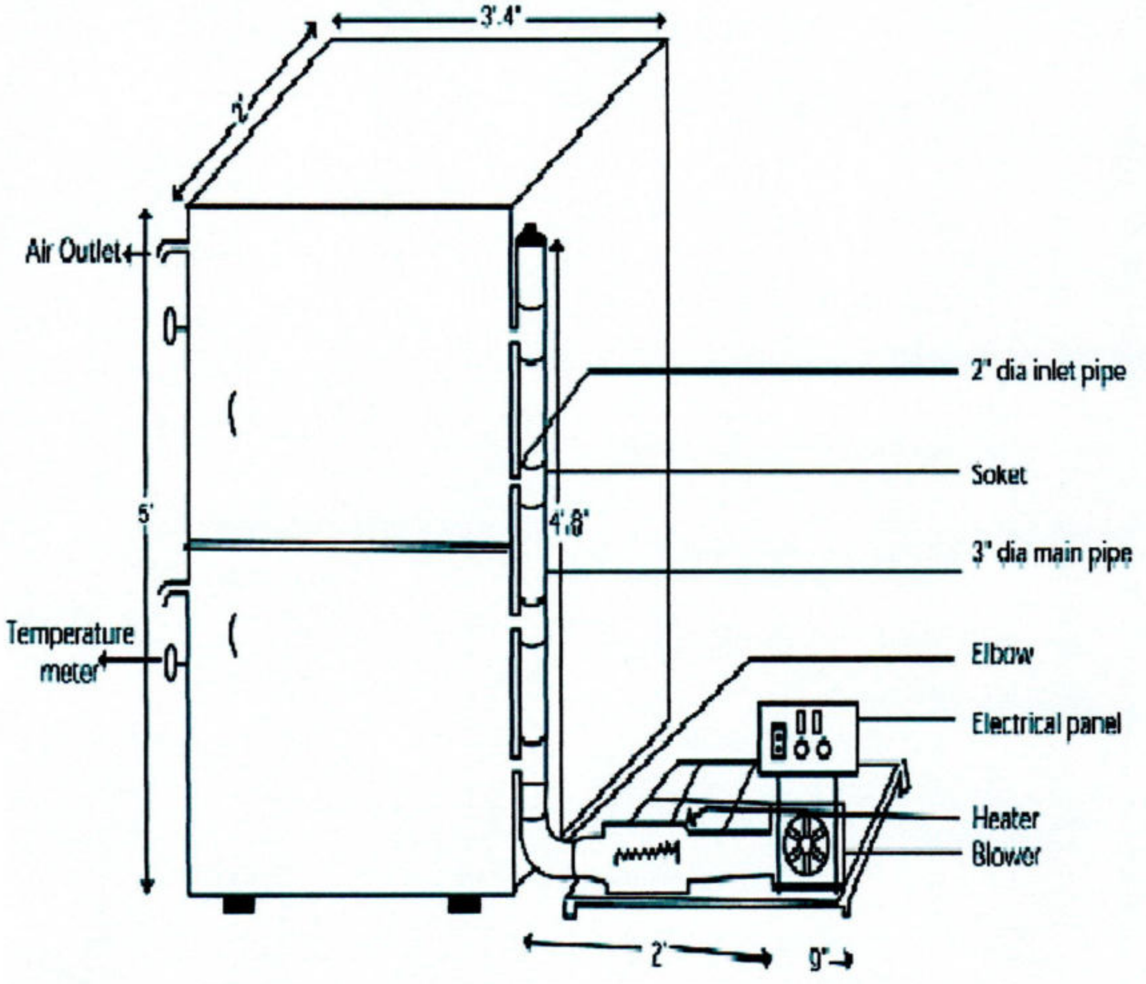

Fig. 3.8: Schematic diagram of a batch type grain dryer

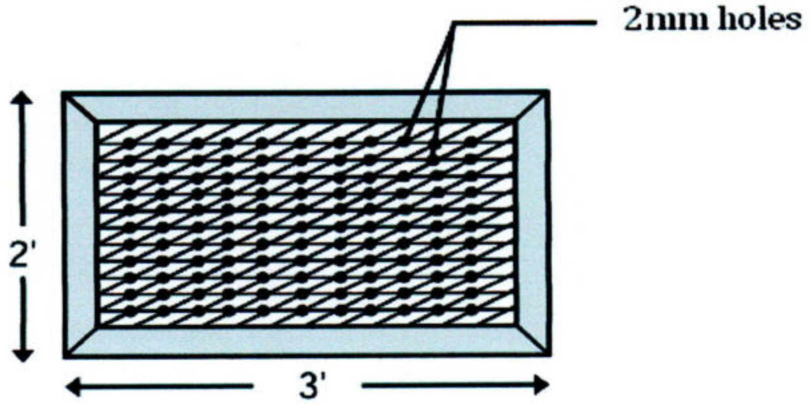

Fig. 3.9: Diagram of a tray

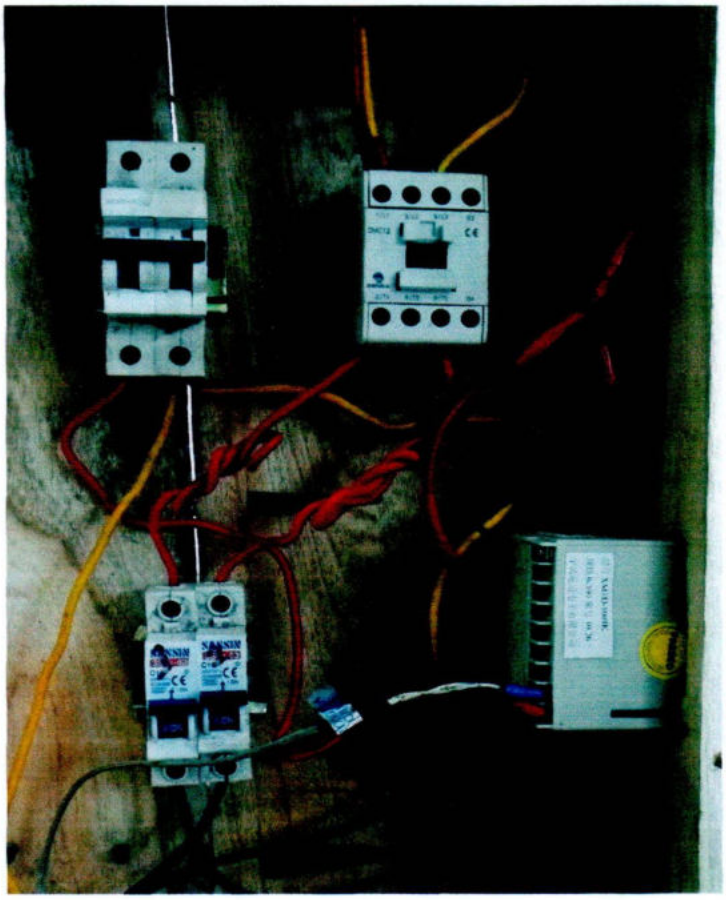

Fig. 3.10: Control system board of the dryer

Fig. 3.11: Switch board of the dryer

Fig. 3.12: Chamber with paddy

Fig. 3.13: Complete assembly of the dryer

Fig. 3.14: Assembly of the dryer chamber

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Working of automatic temperature control system

For the automatic control of temperature inside the drying chamber, thermocouple, temperature controller and magnetic contractor were interconnected with the heaters for on and off the heaters.

The mechanism worked well and switched on and off the heaters at desired set temperature as in the temperature controller. However, there was a difference observed between the temperature of drying chamber and that of the controller. The controller was showing less temperature than that of the drying chamber. This could be due to the location of the thermocouple or small size of the thermocouple. For this reason a calibration curve was drawn between the temperature of the drying chamber and that of the controller when dryer was in unload condition, which is shown in Table 4.1.

Table 4.1: Temperature difference between the dryer chambers and controller.

Time (min)	Temperature (^{0}C)		
	Lower Chamber	Controller	Difference
0	22	16	6
5	33	20	13
10	42	26	16
15	47	31	16
20	51	33	18
25	53	34.5	18.5
30	54.5	35	19.5
35	55	35.5	19.5
40	57	36	21
45	57.5	37	20.5
50	58	37.5	20.5
55	58	37.5	20.5
60	58	37.5	20.5

From the curves the regression equations are developed which could be used for any temperature setup within the range as shown in Table 4.2.

4.2 Calibration to set the temperature of the controller

Because of the temperature difference between dryer chambers and the controller (due to temperature sensor), a calibration was done. Fig.4.1 shows the temperature calibration curve of lower chamber.

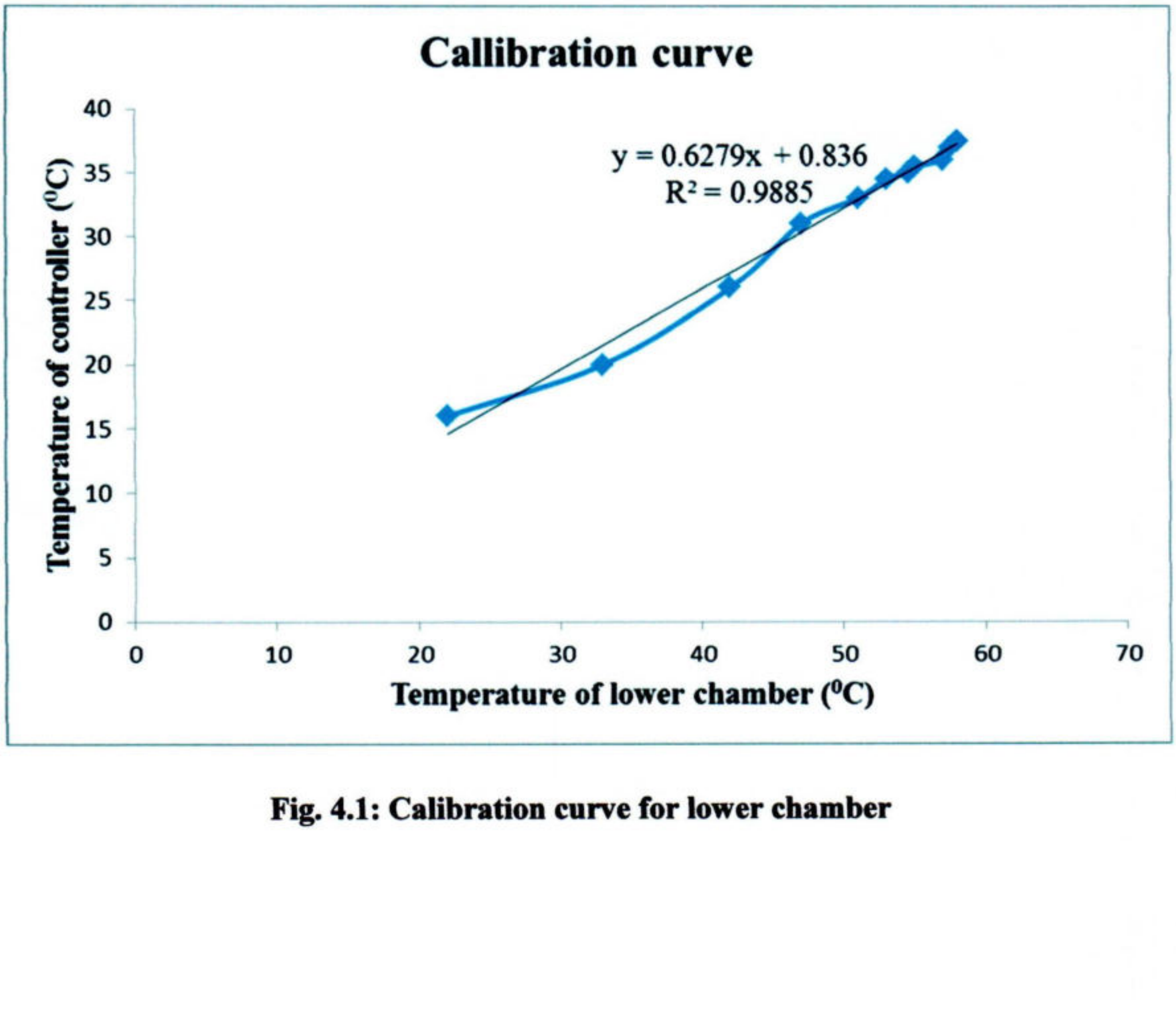

Fig. 4.1: Calibration curve for lower chamber

Table 4.2: Calibration for the lower chamber.

Constant	Temperature of Lower Chamber	Constant	Temperature of Controller
0.6279	x	0.836	y=.6279x+.836
0.6279	22	0.836	14.6498
0.6279	24	0.836	15.9056
0.6279	26	0.836	17.1614
0.6279	28	0.836	18.4172
0.6279	30	0.836	19.673
0.6279	32	0.836	20.9288
0.6279	34	0.836	22.1846
0.6279	36	0.836	23.4404
0.6279	38	0.836	24.6962
0.6279	40	0.836	25.952
0.6279	42	0.836	27.2078
0.6279	44	0.836	28.4636
0.6279	46	0.836	29.7194

The equations from the above figures determine the temperature of the controller to set the required temperature for different chambers respectively. These equations are linear equation.

Where,

x= temperature of the lower/upper chamber

y= temperature of the controller

R^2= Co-efficient of regression

4.3 Experimental results for moisture content of 40 kg Paddy

The freshly harvested paddy had an average moisture content of 25.2% (wb). The paddy was dried for a period of 7.0 hours. During this period both the control system and blower were switched on for 7.0 hours. After 7 hours the control system were switched off. The final moisture content after 7.0 hours was 13.68%, 13.88%, 13.48%, 13.40% shown in Appendix 1.

Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4 show drying curve with time at 60 minutes interval.

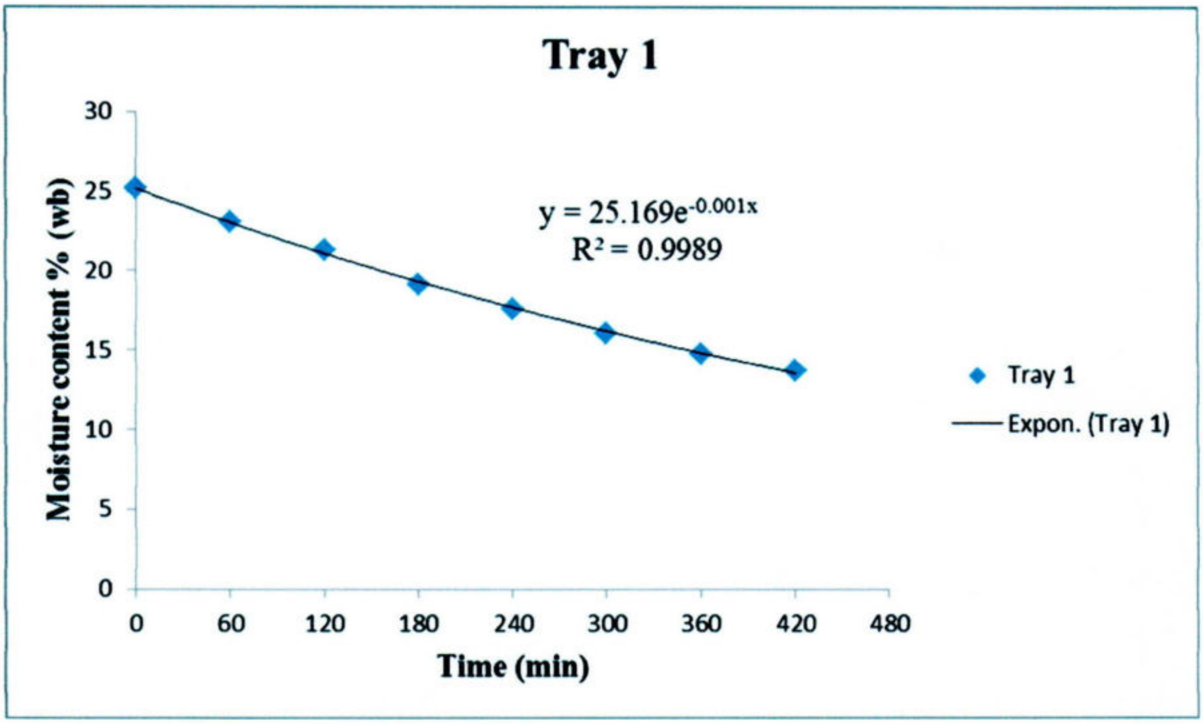

Fig. 4.2: Drying curve for 10 kg paddy in Tray 1

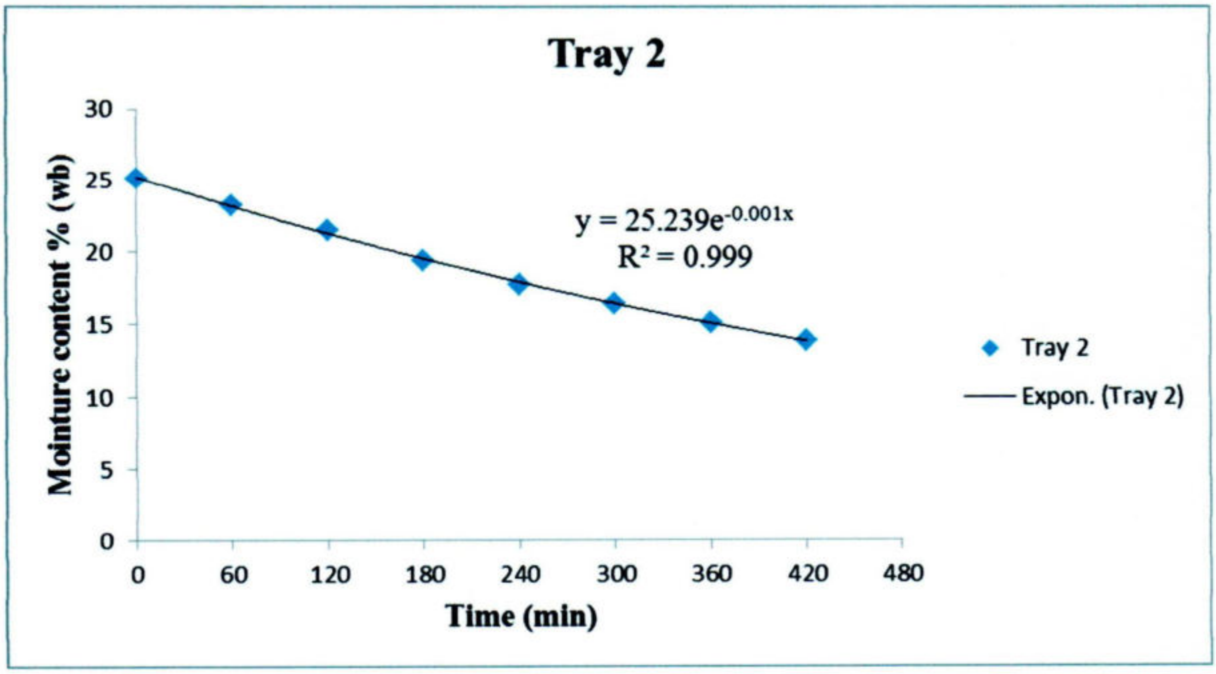

Fig. 4.3: Drying curve for 10 kg paddy in Tray

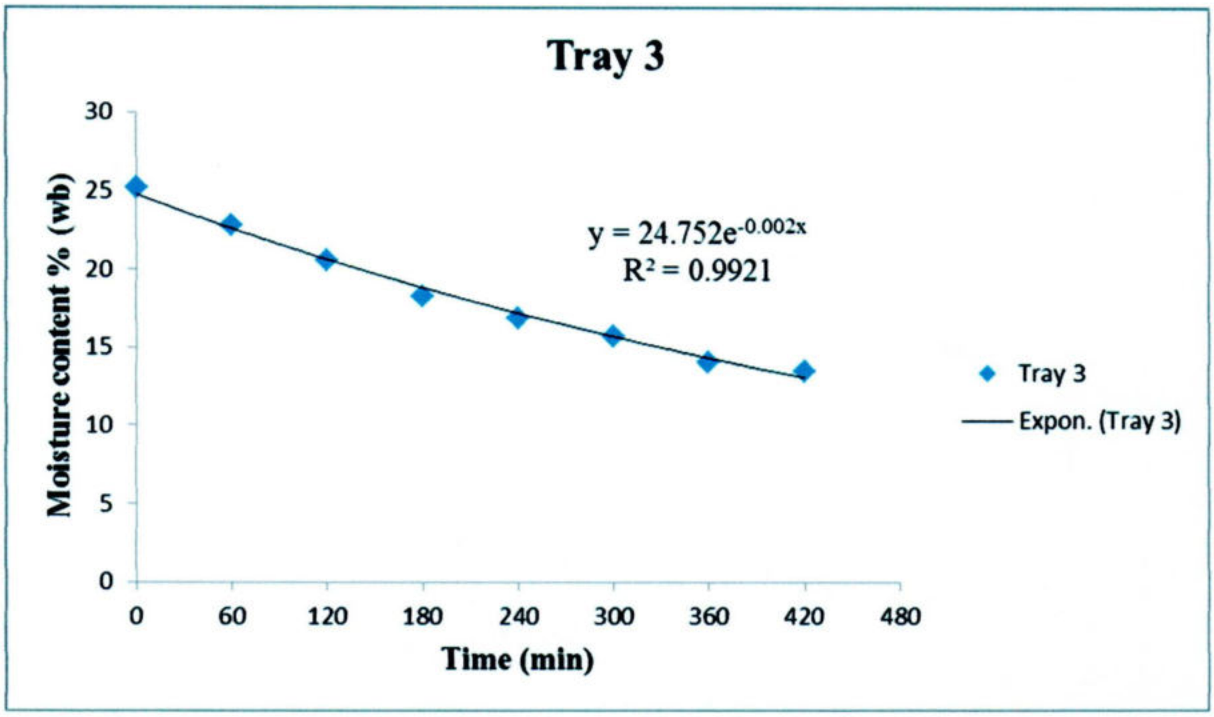

Fig. 4.4: Drying curve for 10 kg paddy in Tray 3

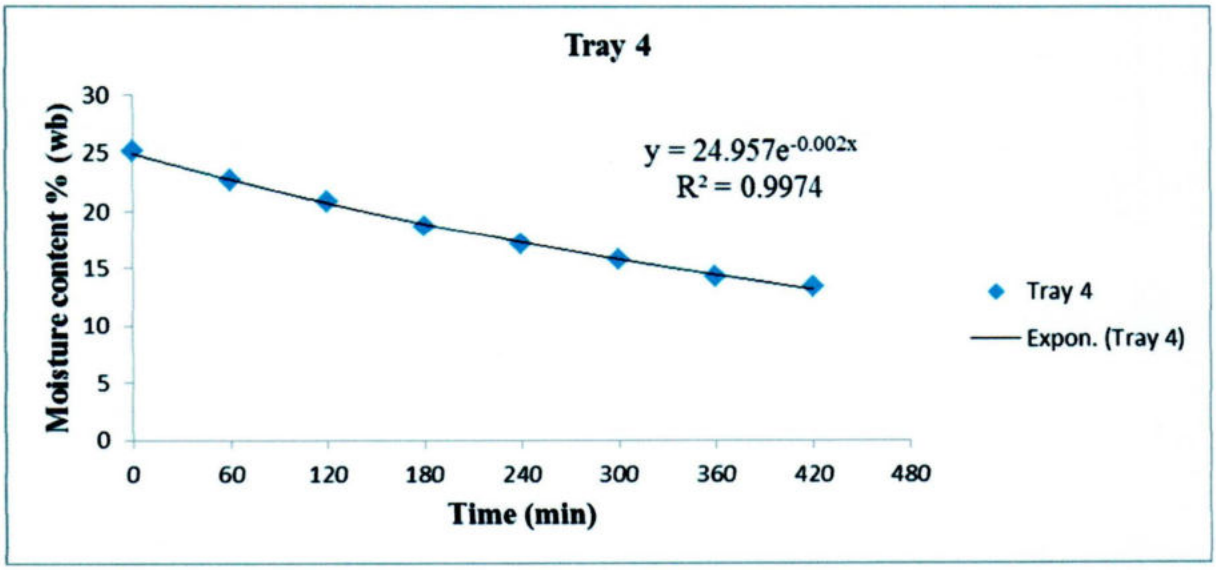

Fig. 4.5: Drying curve for 10 kg paddy in Tray 4

The equations from the above figures determine the moisture content of the paddy at any time for different trays respectively. These equations are exponential equation.

Where,

x= time in minute

y= moisture content, % (wb)

R^2= Co-efficient of regression

4.4 Operating cost of the dryer for 40 kg paddy drying

From the observations it was seen that about 3 hrs required to lower the moisture content from 25.2 to 13.61%. It was found that 7 hrs was required to reduce the moisture content of 40 kg of paddy grain to safe level. So the total operating cost of the dryer will be the combination of 420 watt blower's and 1400 and 1600 watt heaters operating cost. So the operating cost of the dryer for drying certain quantity of grain can be calculated as follows:

Power requirement of Blower = 420 × 7 watt hr

=2940 watt hr

= 2.94 KW hr

= 2.94 unit

Power requirement of both Heater = (1400+1600) × 7 watt hr

= 21000 watt hr

= 21 KW hr

= 21 unit

Total power requirement = (2.94+ 21) unit

= 23.94 unit

Assuming the price of electricity = Tk.6.25/ unit

Then the bill of electricity at one batch = 6.25 × 23.94

= Tk 149.63

So cost of electricity for 1 kg grain $= \frac{149.63}{40}$

= 3.74 Tk / kg

Excluding the labor cost and fixed cost.

CHAPTER V

SUMMARY CONCLUSION AND RECOMMENDATIONS

CHAPTER V

SUMMERY CONCLUSIONS AND RECOMMENDATIONS

A small scale batch type cabinet grain drier was developed for drying grain using locally available materials and a temperature control system was incorporated for increasing the performance of the dryer and reducing operating cost. The overall size of the drier was 5'×3.5'×2'. The total cost of the drier including fabrication was Tk 40,000. Two insulated electrical heaters of 1400 watt and 1600 watt capacity was used for heating air and a 420 watt blower was used to blow air through the heater towards the drier. Different sizes of steel piping were used to convey the hot air to the drier and insulation were done where necessary to reduce heat loss to the atmosphere. Mud cover was used outside the heater chamber for reducing heat loss.

After incorporating the temperature control system, the temperature of the dryer can be controlled by the control system which maintains the safe level of the grain drying temperature between ambient temperature and 60^0C and reduces the cost of power energy.

The moisture content of paddy was reduced by 11.59% (wb) within 7 hrs. The cost of drying paddy was calculated to be Tk 3.74 per kg excluding fixed and labor cost.

From the observations, it was found that it would be possible to increase the air temperature by using better insulator. If auto stirring system could be developed, the drying time would be reduced because during manual stirring the temperature of the drying chamber is decreased due to heat loss.

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APPENDIX

APPENDIX

Appendix 1: Moisture removal rate for 40 kg paddy (10 kg each tray).

Time elapsed (min)	Moisture content % (wb)			
	Tray 1	Tray 2	Tray 3	Tray 4
0	25.2	25.2	25.2	25.2
60	22.8	22.9	22.9	22.9
	23	23.5	23.2	22.5
	23.3	23.3	22.7	22.8
	23.2	23.1	22.6	22.6
Average	23.075	23.2	22.85	22.7
120	21.7	21.9	21.3	20.9
	20.3	21.5	20.1	21.5
	21.1	21.6	21.1	21.4
	22.2	20.9	19.9	19.7
Average	21.325	21.475	20.6	20.875
180	20.9	19.8	19	18.4
	18.5	19.5	17.2	18.7
	18.9	18.7	18.4	18.5
	18.1	20.1	18.6	19.6
Average	19.1	19.525	18.3	18.8
240	16.5	17.5	16.8	15.5
	17.4	17.4	17.6	16.3
	18.7	16.9	15.9	18.7
	17.9	18.9	17.2	17.9
Average	17.625	17.675	16.875	17.1
300	14.9	15.3	14.8	14.5
	17.3	16.3	15.8	16.4
	15.4	17.4	15.4	15.4
	16.9	16.7	16.7	16.8
Average	16.125	16.425	15.675	15.775
360	13.9	14.7	13.8	13.5
	15.5	15.8	14.4	14.9
	14.7	14.4	13.5	13.7
	15.2	15.3	14.7	14.5
Average	14.825	15.05	14.1	14.15
420	13.9	12.7	13.5	13.3
	12.9	13.8	12.5	12.8
	14.2	14.7	13.7	14
	13.7	14.3	14.2	13.5
Average	13.675	13.875	13.475	13.4