DESIGN DEVELOPMENT AND PERFORMANCE STUDY OF A SMALL SCALE GRAIN SEED DRYER

A THESIS

BY

MST. FARHA ANJUM TAPU

Examination Roll No 1505280

Session: 2015-2016

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MASTER OF SCIENCE (MS)

IN

FARM POWER AND MACHINERY

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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Dedicated To

My

Beloved Parents

and

Honorable Teachers

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It is Almighty Allah whose profound blessings and boundless peaces enabled me to complete this research work.

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The author

ABSTRACT

Bangladesh is a tropical country characterized by hot and humid weather. The climatic condition dictates the need for more effective drying of crops, specially, seeds. Seed is the vital input among the main inputs in crop production. Quality seed is important for healthy plant and high yield. Drying is the process that reduces grain moisture content to a safe level for storage. It is the most critical operation after harvesting of a grain. A small scale grain seed dryer was designed and developed in the Agricultural and Industrial Laboratory-1, Hajee Mohammad Danesh Science and Technology University, Dinajpur using locally available materials. The size of the dryer was 1.52 m height and 1.04 m wide. A rotary drum was used inside the drying chamber to keep the seeds drying operation. The drum size was 0.81 m long and 0.41 m diameter. A 0.5 hp motor was used to rotate the drum for auto stirring the grain seed and uniformly drying. In this experiment sample was taken 2 kg, 4 kg and 6 kg paddy seeds and dried in 35^0C, 40^0C and 45^0C temperature respectively. Paddy seeds were also dried in a laboratory dryer at 35^0C, 40^0C and 45^0C temperature to find out the bone dry weight of grain seeds and to find the moisture content. The minimum moisture content of paddy was found to be 9.8% (wb) at 45^0C. The paddy was dried for a period of 6 hrs. Moisture content removal was possible from 14.4% to 9.8% (wb) in 6 hours' time. This dryer was designed for 20 kg of paddy and the total cost of dryer to materials and fabrication was 52,000 Tk. The total drying cost of the dryer 32.47 Tk/kg.

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LIST OF ABREVIATIONS

SL NO.	ABREVIATIONS
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
BJRI	Bangladesh Jute Research Institute
DAE	Department of Agricultural Extension
wb	Wet basis
CSD	Conventional Sun-Drying
BTD	Batch-Type Drier
db	Dry basis
mc	Moisture content
CVS	Computer Vision System
HSI	Hue-Saturation-Intensity
IMC	Initial Moisture Content
FBD	Fluidized Bed Dryer
SBD	Spouted Bed Dryer
ISD	In-Store Dryer
HRY	Head Rice Yield
CSP	Concentrating Solar Panels

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Agriculture is the dominant economic activity in Bangladesh and regarded as the lifeline of the economy of Bangladesh. Its role is vital in enhancing productivity, profitability, income generation, employment and poverty alleviation in the rural areas for improving the livelihood of majority people. Agro-climatic conditions and fertile lands of the country are favorable for growing different kinds of crops round the year. But the country is at present, facing the challenges of increased food production for growing population under stress of decreasing land resources and climate change challenges like drought, salinity, flood, unpredicted rains, tidal surges, cyclone, etc.

Bangladesh is a tropical country characterized by hot and humid weather. The climatic condition dictates the need for more effective drying of crops, specially, seeds (Bala and Hossain, 2001). Seed is the vital input among the main inputs in crop production. Quality seed is important for healthy plant and high yield. Good quality seed can alone increase 15-20% yield of crop. In Bangladesh, about 13% seeds are supplied by government and private sectors and 87% seeds are locally produced and preserved by farmers and local traders (Hossain, 2012). The seeds produced by farmers and traders are not always quality seeds due to high moisture content of seeds. High moisture in seed is the major or single most factors for the loss of seed viability (Stephen and Emmanuel, 2009). The moisture content of grain seeds at harvest is normally 15-18% in winter and 20% or more in rainy season. To minimize the metabolic degradation and to control mold growth, grain seed moisture content should be less than 12%, whereas to control insect infestation, it should not be more than 9%. As the storage conditions at farm level are generally less favorable, seed should be dried to 10% moisture content (Dadalani et al., 2006). The maximum drying temperature range for seed grains is between 40^0-50^0C (Oyoh and menkiti, 2008).

The recent expansion of the private sector seed companies resulted in the engagement of thousands of contract farmers into the formal seed production chain, leading to improved livelihoods amongst the rural community. Government agencies involved in this sector include Bangladesh Agricultural Development Corporation (BADC), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Jute Research Institute (BJRI) and Department of Agricultural Extension (DAE).

Drying is an operation of great commercial importance in agricultural sectors. Modern society requires better product quality, improved safety practices and more environmentally being operations, as well as higher productivity and reduced material wastage. Dying is the process that reduces grain moisture content to a safe level for storage. It is the most critical operation after harvesting of grain. When cereal grain is harvested, it will contain up to 25-35% (wb) moisture in rice crop. Delays in drying, incomplete drying or ineffective drying will reduce grain quality and result in losses (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 whole sale 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).

Due to high moisture content, bacterial and fungal growth is very fast in the grain. Bacteria and enzymes may spoil the foodstuff and reduce the nutrient content in it. Moisture content of crops to a certain level slows down the bacterial, enzymes and yeasts effect. Rice, wheat and corn (maize) are the major cereal grains in Bangladesh. They are vital nutrients for both human and animal populations. At present, the low quality of the seeds of these crops is an important problem facing a large number of farmers. After harvesting, farmers generally store a proportion of their crops for sowing in the next growing season.

Desiccants are chemical substances used as drying agents with a high attraction or affinity for water. They are usually chemically inert and do not react with water or the substances they protect. They use an adsorption mechanism to capture moisture and stow it away where it cannot interact with the product. Industrially, desiccants are widely used in gas streams to control water levels. Silica is the most common desiccant. It is an inert, nontoxic, water-insoluble white solid. Other desiccants include: activated charcoal, calcium sulfate, calcium chloride and molecular sieves (typically zeolites). Desiccant bags like silica bags are used in package contents to protect against humidity during transport and storage. It also helps to prevent corrosion, mold growth and other harmful consequences of moisture through absorption of water vapor. Desiccants are sold in desiccant units. A desiccant unit is the measure of the quantity of desiccant which, at equilibrium with air at 23 ± 35.5°F (2°C), adsorbs the following quantities of water vapor: min. 3.0 g at 20% relative humidity, min. 6.0 g at 40% relative humidity.

Drying of seeds at the farmer level in Bangladesh is normally carried out by the traditional sun drying method, this method is practiced until today for grain because of the advantages of simplicity and economy, but it results in inferior quality of seed due to longer drying time. However, open sun drying has some drawbacks. Open sun drying requires longer drying time and product quality is difficult to control because of inadequate drying, high moisture, fungal growth, encroachment of insects, birds and rodents and others. Open sun drying also requires a large space. Seeds should be dried at constant and optimum temperature. In the present situation dryer is usually used in automatic mill for milling purpose. The price of these dryers is so high for a farmer at rural level to purchase individually. Most of the sensitive crops like rice, wheat, maize, mustard and pulses are easy to damage for high moisture content. In rainy season and winter season, most of the day it is difficult to get proper sun light to dry grain. As a result farmers face problem to preserve their grain. So this is the primary requirement to develop a small scale grain seed dryer.

Different type of dryers have been used in the domestic and industry sectors. Tray dryers, tunnel dryers, drum dryers, fluidized bed dryers, spray dryers, flash dryers, rotary dryers, belt dryers, vacuum dryers and freeze dryer are commonly used. Tray dryer also called cabinet dryer is extensively used because of its simple and economic design. Small scale driers are needed for farmers and small seed business enterpreneurs for processing and drying seeds. This is particularly important for high valued vegetable seeds.

No such dryers are available in Bangladesh for the use of farmers and seed businessman. It is further necessary to develop a dryer which will be used for drying grain seeds uniformly maintain the required temperature and obtainable at low cost.

This is with this aim that this research work was under taken to design, develop and performance study of a rotary type grain seed dryer for drying grain seeds with automatic temperature control system.

The specific objectives of the research work were;

i. To design and develop a small scale grain seed dryer suitable for grain seeds drying.
ii. To evaluate the performance of the dryer.
iii. To determine the optimum drying temperature.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

LITERATURE REVIEW

Drying is the part of agricultural processing involved in the removal of moisture to ensure the safe moisture level by the application of heat. Drying is practiced to uphold the quality of grain during storage to inhibit the growth of bacteria and fungi. The safe moisture content for cereal grains is usually 12 to 14% on wet basis (Bala, 1997). The small farm holdings farmers of Bangladesh usually dry their paddy 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).

Barrozo *et.al.,* (1998) developed and investigated the simultaneous heat and mass transfer between air and soybean seeds in countercurrent and concurrent moving bed dryers by simulation. The equilibrium, heat transfer and mass transfer equations were taken from specific studies. The equation representing drying kinetics was obtained by means of a thin-layer study, whereas the equilibrium equation was chosen from rival model discrimination, based on nonlinearity measures. The simulated results indicated a significant.

Braga *et.al.*, (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.

Tabatabaeefar & Rafiei, (2002) investigated the moisture content distribution across a batch drier. 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.

Prachayawarakorn *et.al.,* (2003) studied fluidized bed paddy drying using super heated steam is a newly alternative approach instead of using the conventional hot air. The mechanism of mass transmission for paddy drying in a range of initial moisture content between 25% and 44.5% d.b. was strongly controlled by internal moisture movement inside the kernel and a two-series exponential equation was aptly used to explain its transmission and temperature and bed depth used as the drying parameter of this equation. The outcome of this experiment showed that head rice yield from super-heated steam drying was more sustainable and had higher values than those from the hot air drying, but the color of the white rice turned into darker making it inferior quality.

Soponronnarit *et.al.,* (2004) studied the simulation and grain quality for in-store drying of paddy. Experiment results from the in-store drying technique using ambient air temperature exposed that the head rice yield, stickiness and whiteness of samples dried from initial moisture contents of 18.5–20.6% to 13.3 ± 0.6% wet basis at temperature of 30 ± 4 °C and specific airflow rates of 0.65–1.5 m^3/min m^2 of paddy reduced however hardness increased. The simulation results showed that the degree of whiteness relied on temperature, relative humidity, loading capacity and airflow rate. The relative humidity lower than 70% and specific air flow rate higher than 0.75 m^3/min m^2 of paddy were suggested.

Phaphuangwittayakul *et.al.,* (2004) studied the performance of a modified batch drier 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 degrees 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.

Madhiyanon & Soonronnarit (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% ([defined as mass flow rate of downcomer air/total mass flow rate of air] x 100%), inlet air temperatures of 110, 130, and 150 degrees C, and initial moisture contents of 18-35% d.b. were used. It was reported that moisture transfer did not only occur in the spout region but also took place in the downcomer region. 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.

Bockelmann *et.al.*, (2005) investigated the possibilities of optimizing the process combination of warm-air drying and microwave tested for grain maize. The combination of these two techniques made 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.

Oberoi *et.al.,* (2005) investigated freshly harvested red chilli (Capsicum annuum cv. CH-3) subjected to conventional sun-drying (CSD) and drying in the batch-type drier (BTD) using indirect hot air. The two 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. There was nearly a 2 log (cfu/g) reduction in total bacterial count in drier-dried chillies compared to sun-dried ones but no difference in the lactobacilli colonies could be observed. A marked reduction in yeast and fungal colonies in drier-dried samples compared to sun-dried samples could be seen. Escherichia coli and Salmonella were not observed in dried chilli samples using either of the drying methods. The results indicated that chilli dried in a BTD was better with regard to physico-chemical characteristics and relatively safe with respect to microbiological quality.

Descoteaux & Savoie (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 vapour 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% w.b. and finally exceeded 4% at moisture contents below 15% w.b. 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% w.b., 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.

Rostami *et.al.,* (2006) investigated 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 (m.c.) 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, 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.

Lacerda *et.al.*, (2006) investigated a system for coffee drying, using partial drying in a fixed bed drier and complementary drying in an intermittent concurrent flow batch drier. The experiment was carried out in the Vegetable Products Processing Area, DEA-UFV, Brazil. The drying tests were accomplished in completely randomized design. The coffee was harvested on the ground by manual stripping process. The fruits were pre-processed by drying of ripe, overripe and greenish cherries. For the preliminary drying, the initial coffee moisture content varied from 68.9 to 71.3% w.b. with the drying being interrupted with moisture content between 44.0 and 47.5% w.b. In the complementary drying phase, the final moisture varied between 12.2 and 13.8% w.b. The temperature of the drying air in the fixed-bed drier varied from 50.4 to 76 degrees C, and in the concurrent flow batch drier, between 87.2 and 110 degrees C. The specific enthalpies were 8.4 to 9.1 MJ kg^{-1} and 7.1 to 16.9 MJ $kg^{-1}$for the fixed-bed drier and concurrent flow batch drier, respectively. In comparison with the control tests, the final quality of the product presented better commercial characteristics. It was concluded that with preliminary drying in fixed bed drier and complementary drying in a concurrent flow drier, besides reducing the total drying time, the combined system contributed to a better preservation of qualities acquired in the field.

Martynenko, (2006) described a computer vision system (CVS) for control of the drying process with a portable CCD camera with IEEE-1396 interface and configurable software Lab View 7.0 and IMAQTM 6.1. An object area was continuously monitored through the CVS by extracting the green plane from the RGB color space followed by thresholding and pixel counting. An object color was continuously monitored through the CVS as color intensity in the hue-saturation-intensity (HSI) color space. The observability of a drying process was provided due to on line image analysis and correlation of image attributes (area, color, and texture) with physical parameters of drying (moisture, quality). A relationship between area shrinkage and moisture content was used for on line estimation of actual moisture content. A relationship between color intensity and quality was used for on line estimation of quality degradation. Experimental study of the CVS for drying of ginseng (Panax ginseng) from Ontario, Canada, showed advantages of computer vision for on line monitoring of important state variables, such as moisture content and material quality. Color measurements demonstrated high sensitivity of quality to drying conditions. Drying at 50ºC resulted in significant color changes and unacceptable quality degradation. The quality of roots in three-stage (38-50-38 degrees C) drying process was compatible with recommended isothermal (38 degrees C) drying due to significant (30-40%) reduction of drying time. This control strategy was used in a pilot batch drier for temperature control with respect to quality. Testing of a pilot drier with embedded CVS proved stability and robustness of control strategy, combined with high accuracy in the estimation of moisture content (8-14% of error with 95% confidence). The composite moisture measurements at the endpoint demonstrated uniform drying of root mixture to target moisture content 0.1 g/g (db) with minor variations between individual roots in the range of 0.07-0.12 g/g.

Lamlerd *et.al.*, (2007) investigated the rotary dryer of paddy by using Closed-loop oscillating heat pipe with check valves (CLOHP/CV) heat exchanger. The working fluids used were R134a, ethanol and water with a filling ratio of 50 % of the total volume and operating conditions with inlet hot gases from used oil burner. At evaporator section the hot gas velocity was set at 0.5, 1 and 1.5 m/s. Experimental results found the R134a with 0.5 m/s as appropriate parameter values for using in drying the paddy, the moisture content of paddy with initial moisture content of 24.8% wb decreased to 17.5% wb.

Marek *et.al.,* (2007) investigated the drying characteristics of barley grain dried in a spouted-bed and combined IR-convection dryers. Barley grain dried in a laboratory scale spouted-bed dryer at 30, 35, 40, and 45°C and an inlet air velocity of 23 m/s^{-1}, and in an IR-convection dryer under an infrared radiation intensity of 0.048, 0.061, 0.073, and 0.107 W cm^{-2} at an air velocity of 0.5 m/s^{-1}. The results show that the first, relatively short, phase of a sharp decrease in the drying rate was followed by the phase of a slow decrease. The time of barley drying depended on temperature of inlet air in a spouted-bed dryer and on radiation intensities in an IR-convection dryer. Barley drying at 45°C in a spouted-bed dryer was accompanied by the lowest total energy consumption. The average specific energy consumption was lower and the average efficiency of drying was higher for drying in a spouted-bed dryer. The effective diffusivities were in the range 2.20–4.52 × 10^{-11} m^2 s^{-1} and 3.04–4.79 × 10^{-11} m^2/s^{-1} for barley dried in a spouted-bed and in an IR-convection dryer, respectively.

Gaese *et.al.,*(2008) conducted an experiment with various box type paddy dryers. The objective of the experiment was to assess the technical performance of the dryer and physical characteristics of the rice were also analyzed and outcomes were compared with milling yield between box dryer and sun dryer. Experimental results showed that there was no significant difference in quality testing between the milling yield from the paddy dried in box dryer and from the paddy dried under sun drying. The installation cost of the dryer was large which was not possible to carry for the farmer.

Kimura *et.al.,* (2009) carried out an experiment to observe the effect of the use of discharge fan with different heights of paddy on the drying effectiveness. In Iran, rice was dried until the moisture content reached to 6 -8% by flat bed dryer. Drying time saved in the range of 10-20% and temperature distribution efficiency increased 17-26% by the application of discharge fan. The grain was breakage because of the non-uniform distribution of the temperature between the layers of the grain.

Adzimah & Seckley, (2009) investigated the improvement on the design of a cabinet grain dryer. The dryer consists of a cabinet containing trays in which the grains to be dried are spread. After the grains were loaded, the cabinet closed and heated air of about 35-40°C blown across the grains. Heat was supplied by an electrical heating coil and hot air was blown from the heater housing to the drying chamber by the aid of a fan. The dryer also consisted of a thermostat which turns off the machine if inlet temperature exceeds 40°C. It takes 6-12 h to complete the drying process. In the research that follows, effort is made to reduce drying time to about 2 h.

Irtwange & Adebayo, (2009) development and performance studied of a laboratory-scale passive solar grain dryer in a tropical environment. The dryer consisted of a solar collector panel, a thermal storage unit and a drying chamber. The top of the collector is made of one layer of 4 mm thickness of colourless glass sheet as glazing. The absorber material used was corrugated 0.5 mm thick zinc roofing sheet painted black. The thermal storage unit and the drying chamber were built of wood because of its good insulation properties. The dryer was evaluated using 10 kg of freshly harvested maize at 32.8%wb. The performance evaluation results obtained showed that the mean drying rate of the dryer was 0.7 kg/day per every 10 kg of corn whereas sun-drying rate was 0.3125 kg/day comparatively. It took 4-days to dry the corn to moisture content of 13.1%wb using the passive solar dryer while it took 8-days to dry to 13.4%wb under sun drying. Commercial sizes of the solar dryer can be amplified and produced for community level cooperative use and for prospective investors to fast track agricultural development in the rural areas.

Ruifang Wang *et.al.,* (2009) studied about the soybean drying characteristics in microwave rotary dryer with forced convection. In a laboratory microwave rotary dryer, rewetted soybean was utilized as experimental material to study the effects of drum rotating speed, ventilation flow rate, and specific microwave power on the drying kinetics and cracking ratio of soybean. It was found that, with rotation, the cracking ratio could be lowered but without distinct improvement in the drying rate. Increasing ventilation flow rate and specific microwave power can improve the drying rate, but the cracking ratio also increases as a negative result. The cracking ratio lower than 10% can be attained for ventilation flow rate lower than 2.0 $m^3 \cdot h^{-1}$ or specific microwave energy lower than 0.4 $kW \cdot kg^{-1}$ in the present experiments.

Mauromoustakos *et.al.,* (2010) investigated the application of Low-temperature (26-34^{0}c), low-relative humidity (19-68%) to dry thin layer samples of rough rice to the desired 12.5% moisture content. The quality parameters of head-rice yield of long and medium grain rice cultivars harvested at 19.6% and 17.5% moisture contents, respectively, were determined. The experimental result showed that use of Low-temperature and low-relative humidity had no adverse effect on head rice yield.

Hassan, (2010) studied the drying and quality evaluation of paddy seeds in hybrid dryer. Quality seeds could alone increase 15-20% yields of the crops. So, Optimum drying temperature of paddy seeds was necessary and at 44^{0}C drying temperature was completely safe for paddy seeds. The maximum average germination percentage and viability of dried paddy seed were 86% and 98% respectively after drying paddy seeds at 44^{0}C. The average air temperatures at collector outlet and inside the drier were found about 22.71°C and 17.22°C higher than the average ambient air temperature, respectively. The collector efficiency varied from 20% to 32% depending on the global solar radiation. The experimental data was fitted to nine thin layer drying equations. A non-linear regression analysis was used to fit the thin layer drying equations.

Pfeifer *et.al.,* (2010) modeled soybean seed drying in concurrent sliding bed dryers. Sliding bed dryers was frequently studied for the drying of seeds because they caused mechanical damage to seeds. The effect of the number of stages of a concurrent sliding bed dryer on the soybean seed quality and drying performance was studied. The so-called two-phase model was used to describe heat and mass transfer between air and soybean seeds. Seed quality was evaluated by vigour and non-fissured seed indices. The simulated results showed that by dividing the air supply in several stages (2, 3 or 4) the drying performace was not good.

Jittanit *et.al.,* (2010) investigated the fluidized bed dryer by drying corn, rice, and wheat seeds with an initial moisture content (IMC) of 20–25% wb. Moisture content below 18% wb at 40–80°C in a fluidized bed dryer (FBD) and spouted bed dryer (SBD) and the seeds with IMC 18% wb were dried to below 14% wb at air temperatures 18–30°C and relative humidity 60–70% by an in-store dryer (ISD). As a result, it appeared that a two-stage drying concept was feasible in drying high-moisture-content seeds due to the high germination rate of dried seeds. Nonetheless, the drying temperature must be carefully selected. A drying temperature of 40°C was clearly safe for all samples, whereas more than 90% of wheat seeds still germinated after drying at 60°C in FBD. Furthermore, drying seeds with IMC 18% wb by ISD was safe under specified drying conditions.

Banisharif *et.al.,* (2012) conducted an experiment about mathematical modeling of fluidized bed drying of rough rice (*Oryza sativa* L.) grain. Different air temperatures of 50, 60, and 70^0C, superficial velocities of 2.3, 2.5, and 2.8 m/s were applied for the drying of paddy. Different empirical and semi empirical drying model were applied to fit the data. Midilli *et al*. (2002) model was the best model in describing fluidized bed drying characteristics of rough rice. Experimental results revealed that drying air temperature had a significant effect on drying kinetics. The drying rate increased marginally with the increase of air temperature while the drying rate decreased marginally with the increase in the solids holdup.

Tirawanichakul *et.al.,* (2012) studied the effect of infrared (IR) and hot air (HA) drying conditions on drying kinetics of Leb Nok Pattani (LNP) rice and Suphanburi 1 (SP 1) parboiled rice and their qualities. Application of Drying temperatures of 60-100°C, IR power of 1.0 and 1.5 kW and hot air flow rate of 1.0±0.2 m/s showed that HA and IR parboiled rice drying could maintain high head rice yield (HRY) and additionally, the qualities analysis showed that whiteness, water absorption, cooking time and pasting property were significantly different compared to reference samples. The specific energy consumption of parboiled rice drying with IR of 1.0 kW at 100°C delivered a low value.

Hossain *et.al*., (2012) developed and performance evaluated of hybrid dryer for quality grain seeds.The technical performance of the dryer was tested for drying of different grain seeds and seed quality was evaluated during the period of 2010-2011. The reflected solar radiation was 53% of global solar radiation. The thermal efficiency of the collector was 28.73%. The dryer was tested for drying of paddy, wheat, maize and groundnut seeds. Times required for drying of 250-300 kg of paddy, 250 kg of wheat, 350 kg of maize and 200 kg groundnut seeds were 17, 12, 16 and 20 hours, respectively. For the tested grains, seed germinations were above 90%, viabilities were about 85% and vigor indices were above 1.0. Therefore, it is evident from the test results that good quality seeds were produced through drying them in the hybrid dryer. The benefit cost ratios (BCR) for drying of paddy seeds was 1.40. The payback period of the dryer was 0.44 year.

Lilhare *et.al*., (2012) worked on drying rate analysis of different size paddy processed under various drying conditions in L.S.U dryer. The drying time for different size paddy in different ambient conditions have been measured. From obtained data drying rates are calculated.

James *et.al.,* (2012) studied the performance evaluation of an enhanced fruit solar dryer using concentrating panels. Concentrating solar panels (CSP) improve the process of solar drying Roma tomatoes. Temperatures inside the dryer that utilized the concentrating solar panels were approx. 10 °C higher than those in the normal dryer during the majority of a sunny day testing period. This increase in temperature led to shorter Roma tomato drying times in the dryer with CSP. The concentrating solar panels showed a considerable increase in drying rate on sunny days, with a 27% decrease in total drying time as compared to the normal dryer to reach the target dimensionless moisture content of 0.2.

Souza *et.al*., (2013) evaluated the drying of soybean seeds in a fixed bed dryer, considering the heterogeneity of the process and the effect of process variables on seed quality. Seed and air temperatures, seed moisture, and seed quality were measured through the bed. The fixed bed dryer used by Souza consisted of a conical region consisting of a porous medium for air distribution and a 0.25m diameter and 0.6m high cylindrical drying zone. Moreover, seed quality indices are highly sensitive to variations in drying temperatures (F1). The best results (i.e., the least damage to seed quality) were obtained at the lowest drying air temperatures (F1¼_1.41 or Tf¼32.9_C).

Fashina *et.al.,* (2013) studied the design parameters for a small-scale batch in-bin maize dryer. Early season maize was harvested with high moisture content that makes it impossible to store. The sale of early season maize in green form was uneconomical to the farmer. Also, grain losses were high when maize is harvested green. To minimize grain losses and thereby increase value and the profit margin of the farmer, a grain dryer was necessary for wet grains. Some properties of maize such as moisture content and bulk density were determined to get information required for design of the dryer. The dimension of drying chamber, amount of moisture to be removed in a batch, quantity of air required to effect drying, volume of air required to effect drying, blower capacity, quantity of heat required to effect drying and actual heat used to effect drying were all designed for. A maize dryer was developed with a batch size of 100 kg of threshed wet maize. The dryer can be used in laboratory for experimental purpose as well as on the farm for commercial purposes. The dryer can be used to measure drying rates of maize at different initial moisture contents, drying air temperatures, drying air velocities and grain beds. The effects of different drying temperature, air velocity, loading and agitating speed on the quality of dried maize can be investigated with the dryer.

Chaurlyisky *et.al.,* (2013) investigated the drying of seeds from common wheat (*Triticum aestivum L.*) by using Silica gel for ex situ storage. One of the most widely used methods for maintenance of the biodiversity of the cultural plant species was their preservation under ex situ conditions. This major approach was related to storage of accessions at organism level in genetic stock centers by reducing the metabolite activity of the seeds as a result of low moisture content and low temperature. When working with a small number of samples in long term storage collections, a suitable method for reduction of moisture was used to desiccant Silica Gel. Seeds from three contemporary cultivars of DAI were used, Aglika, Enola and Pryaspa, which were grown in 2012. The experiment was designed at three different volumes of grain:desiccant ratios: 1 part grain to 0.5 parts silica gel (1:0.5), 1 part grain to 1 part silica gel (1:1), and 1 part grain to 1.5 parts silica gel. Moisture content in seeds was determined by a weight method. The first reading was done on the 30th day, the second and third – at 20 day intervals. Two-factor dispersion analysis and variation analysis were applied for statistical processing of the data with the help of the software XLSTAT Pro ver. 7.5.2. The lowest moisture content at the end of the experiment was determined for cultivar Enola: 5.2 % at ratio 1:1.5 grain seeds/silica gel. It was found that at variant 1:1.5 seeds/silica gel the lowest moisture levels were reached and moisture reduction was the fastest. The experimental result shows that use of low temperature and low moisture content had no adverse effect on wheat yield.

Diaz *et.al.,* (2013) carried out an investigation to determine the coffee bean rotary dryer operating conditions that minimized the energy consumption (Q) and maximized the process thermal efficiency. A mechanistic coffee bean drying model was solved for a complete mixed assumption to simulate the drying. The simulated results reproduced the experimental results obtained with a 7.60 m^3 Guardiola dryer loaded with 2675 kg of wet green coffee grains. The thermal second law efficiency of the drying was calculated with an expression that takes into account the exergy air carries before entering the dryer. For the same coffee load, and with restrictions on grain's temperature (T_ <45_C), final water content (X_ <11%) and water activity (aw <0.80), the drying was simulated for several air fluxes and temperatures to find the optimum drying conditions (T =80_C and G =6560 kg air.h□1). A 15.80%reduction in energy consumption was achieved when optimization results were compared with the normal operation conditions.

Misha *et.al.,* (2013) reviewed on the application of a tray dryer system for agricultural products. Tray dryer was widely used in agricultural drying because of its simple design and capability to dry products at high volume. Implementing the proper design of a tray dryer system might eliminate or reduce non-uniformity of drying and increases dryer efficiency. Computational fluid dynamics simulation is a very useful tool in the optimization of the drying chamber configuration by predicting the airflow distribution and the temperature profile throughout the drying chamber.

Roman, (2014) investigated the influence of design parameters of rotary dryer on sunflower seeds drying, in order to improve the drying of sunflower seeds in the apparatus of the rotary type. Rotary dryer consisted of three chambers: the upper drying, the middle drying and the lower cooling. Mathematical models were obtained that showed the dependence of pressure of coolant (air) in the drying chamber of rotary dryer on the rate of the coolant. The design of rotary dryer was improved by providing the tangential supply of coolant and installing a spiral partition under gas distribution grid. The speed of the coolant should be 1...2 m/s, the open area of the grid through which the coolant passes should be 0,01...0,05%, the grid resistance during the passage of air through the openings should be 0,75...0,9. High speed contributes to a sharp increase in energy consumption. The seeds moisture decreased from 18…20 to 5...9 % per cycle duration approximatly in 8 min. (drying 4-5 min., cooling 2-3 minutes.) without degradation of the quality of seeds during the drying of sunflower seeds in a rotating dryer at a temperature of coolant 160...170 °C and the height of layer 250 mm. In addition, this method of drying significantly reduces the seeds infestation.

Thomas & Zhongjie, (2014) worked on opportunities for the development of heat pump drying systems. It was discovered that heat pump drying was an efficient method of drying for drying industries. Heat pumps deliver more heat during the drying process than the work input to the compressor. Heat pump dryers provide high energy efficiency with controllable temperature, air flow and air humidity and had significant energy-saving potential. In the last decade the market for heat pump systems for water heating and space cooling/heating was grown in South Africa, but the development of heat pumps for industrial and agricultural drying was very slow. As a result of high increases in fossil fuel prices and electricity in South Africa, as well as the problem of CO_2 emissions, green energy, energy saving and energy efficiency were imperative.

Mangesh *et.al.,*(2015) investigated the design and development of solar seed dryer. A small scale village level solar dryer for tomato was developed under Yola weather at latitude 9°14′ N and longitude 12°26′ E using locally available materials and the performance was evaluated. On the similar approach manufactured seed dryer which were also more useful for drying the seeds, crops i.e. maize, beans etc. The essence of the dryer was to achieve the effective method of seed preservation and eliminate the drudgery and product deterioration associated with traditional methods of open sun drying of seed. This were in view of alleviating the weather limitation experienced by farmers in crop drying especially for tomatoes. The solar dryer consisted of tray, reflective walls and glass roof, a preheating air absorber plate, inner panels for removal of moisture and chimney through which air stream passed across the dryer. Evaluation of the dryer showed a raised temperature of about 47^0 attainable in the drying chamber. The dryer temperature and drying rate was found to be higher than the natural open sun drying method. Typical drying times in solar dryers ranged from 1 to 3 days depending on sun, air movement, humidity and the type of food to be dried. In the rainy and winter seasons no protection from rain or dew that wets the product, encouraged mould growth and might result in a relatively high final moisture content; low and variable quality of products due to over or under drying.

Sidrah *et.al.,* (2015) designed, developed and performance studied of a small-scale solar assisted paddy dryer for on farm processing. Particularly important for developing countries where post-harvest losses of cereals are between 10-20% and of fruits and vegetables as high as 20-100%. A new solar assisted paddy dryer with central air distribution model (along the length of drying chamber) was developed. Due to this distinct feature of the dryer, high drying rate was achieved during the drying processes .Other components of the dryer were perforated drying chamber, blower and flat plate solar air collector. Dryer was evaluated using 100kg of freshly harvested paddy at 23.78% moisture content (wb). Performance evaluation results showed that the mean drying rate of the solar assisted paddy dryer was 0.87 kg/hr for every 100 kg, whereas 0.46 kg/hr was the sun drying rate comparatively. By using the solar assisted paddy dryer, approximately 50% saving in time was also achieved as compared with the traditional sun drying method. Solar assisted paddy dryer took 10 hr for drying the 100 kg paddy up to 14%, while sun drying method dried paddy up to 13.89% in 19 hours. For development of agriculture in the rural areas, commercial size of the solar assisted paddy dryer could be amplified and produced at community level.

There are numerous mechanical dryers for paddy drying for industrial purpose that require a vast capital investment. After harvesting of cereal grain a large portion of it is destroyed due to lack of drying or proper processing in rural areas and if it is possible to develop a small scale grain dryer, a significant grain loss might be minimized that will contribute to the economy of the country.

CHAPTER III

MATERIAL AND METHODS

CHAPTER III

MATERIALS AND METHODS

Theoretical consideration, materials used to develop the dryer, design and construction of different parts of the dryer and performance of the dryer were desceibed in this chapter. The dryer was made of locally available materials. It was fabricated at Shurovi Engineering Workshop, Pulhat, Dinajpur. Drying experiments for the dryer were performed in the Agricultural and Industrial Engineering Laboratory-1 of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur.

3.1 Theoretical consideration in designing a grain seed dryer

3.1.1 Basic principle of grain drying

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 in the drum. 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 air drying temperatures. Systems are needed to establish the control of amount of air flow and also to control the hot air temperatures. Automatic temperature control system need to be established to maintain the suitable temperature for different kinds of seed grains. Insulation of the heating surface is required to reduce the loss of heat to the atmosphere. When drum rotated then stirring system is occurred automatically and the grain is drying properly. In this research work, a small scale grain seed dryer was designed and improved on the basis of the above basic theories using locally available materials. The dryer size was designed on the basis of drying 20 kg of grain at a time.

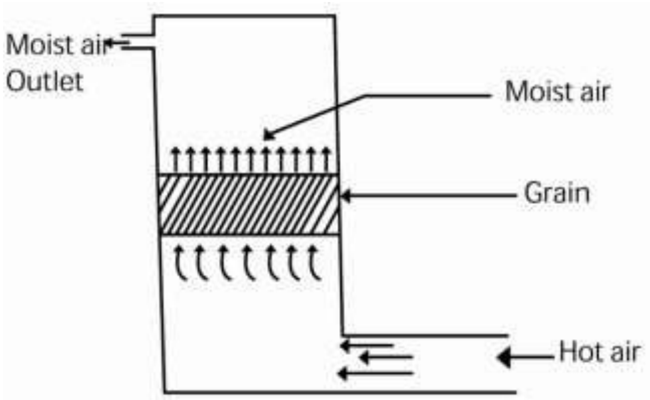

Fig -3.1: Basic principle of grain drying

3.1.2 Drying curve

A drying curve, as illustrated in the figure below, shows how the grain moisture content changes over time and how grain temperature changes. As can be seen in the chart, the drying rate is not constant but changes over time. The temperature of the grain equally changes over time.

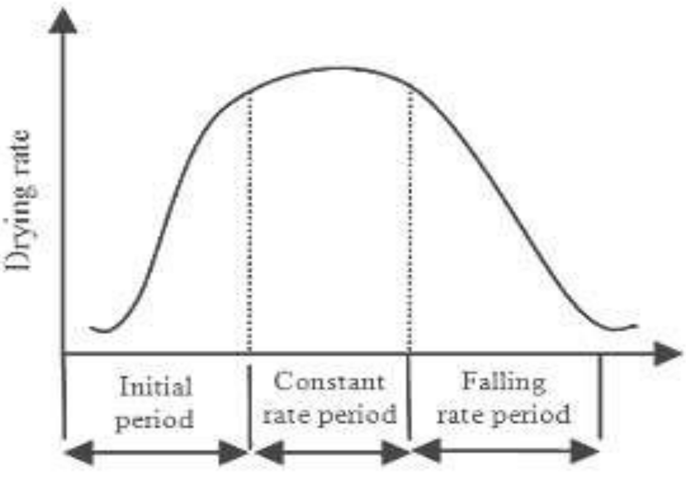

Fig-3.2: Drying curve

There are three different periods which will occur consecutively in time (IRRI 2013):

1. Preheating period (drying rate is slowly increasing): When wet grain is exposed to hot air, initially only a very slight change in MC is observed. This happens because all the heat provided in the drying air is used to heat up the grain to the drying air temperature.

2. Constant-rate period (drying rate is constant in time): Once the grain is at the drying temperature, water starts to evaporate from the surface of the grain. During this period, all the heat from the drying air is used to evaporate surface moisture and the amount of moisture removed from the grain is constant in time. It is therefore called the constant-rate period. During this period, grain temperature is constant as well.

3. Falling-rate period (drying rate declines over time): As time passes, it takes more time for internal moisture to appear at the surface, and evaporation of water is no longer constant in time. As a result, drying rate declines, and some of the heat from the drying air will heat up the grain. For paddy grain, the falling-rate period typically occurs at around 18% grain moisture content.

3.2 Materials used to develop the dryer

Following materials were collected to develop the dryer from local market:

i. M.S sheet
ii. M.S angle bar
iii. UCP block bearing 210
iv. Motor (0.5 hp)
v. Gear box
vi. Pulley
vii. V- belt
viii. Chain
ix. Pinion
x. Nuts and bolts
xi. Tool box

Instruments used to conduct experiments for the developed dryer:

i. Digital moisture meter.
ii. Temperature and Vane anemometer.
iii. Electronic balance.
iv. Oven Dryer.

3.3 Design and construction of different parts of the dryer

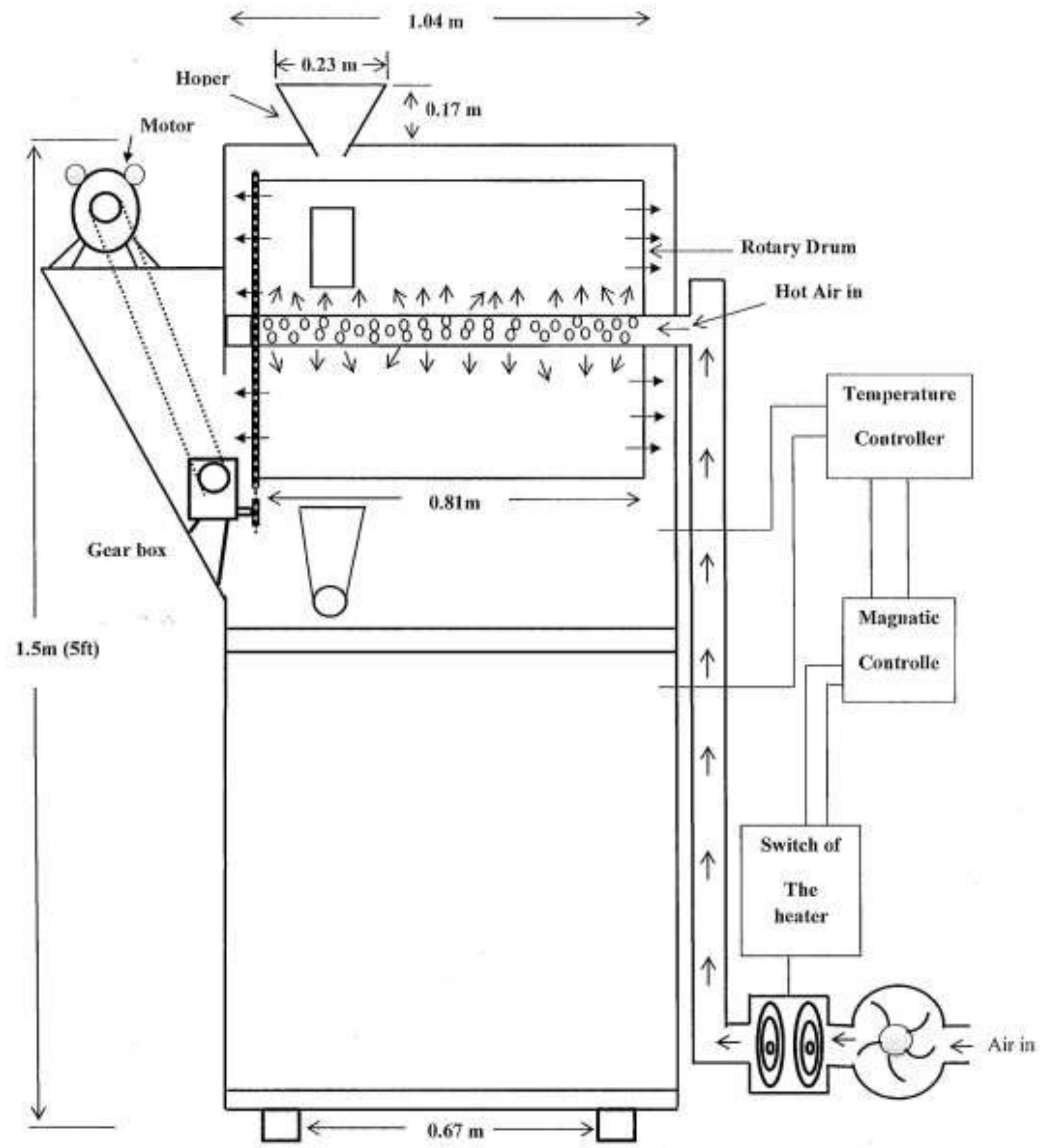

Fig-3.3: Schematic View of the Dryer

Fig-3.4: Complete assembly of the dryer

3.3.1 The drying chamber

A structure was made using 1.5 inch (3.81cm) angle bar. It was shaded with plane M.S. sheet to give a total size of the dryer to be 1.52 m high and 1.04 m wide. There were two cabinets or chambers in the dryer respectively the upper chamber and the lower chamber. In the upper cabinet a drum was used to hold the grain. The drum was rotated by an electric motor and gear. The size of the drum was 32 inch (0.81 m) length and 18 inch (0.41 m) diameter. Inside the drum, one 2" (5.08cm) pipe ran from one side to other with 1.2 cm holes made around the pipe which carries hot air into the drum from the outside 3" (7.62cm) duct.

3.3.2 Hot air supply system

A structure was made using angle bar to support a blower of 420 watt. The regulator could be adjusted to increase or decrease the amount of air flow. Two insulated electric heaters of respectively 1400 watt and 1600 watt 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 outside of the heater chamber was covered with earth work to reduce the heat loss. The main duct or 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 1.22 m. From this vertical pipe two openings were made and connected with suitable connectors to the 2 inch pipes of the drier cabinets. The 3 inch main duct was insulated by using cork sheet of 2 mm thickness to reduce heat loss to the atmosphere.

Fig-3.5: Hot air supply pipe

3.3.3 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. Enough holes were made on both sides of the drum for exit of the air. Total area of the hole was 2.54 in^2 $[\{\pi(3mm)^2 X40\}+\{\pi(.75mm)^2 X194\}]$. 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.

3.3.4 Measurement of drying air temperature

To measure the temperature of the air, inside the dryer, thermometer was set on the wall of the drum of the dryer. The thermometer was of stainless steel made in China and capable to measure temperature up to 150^0C with a resolution of 1^0C. 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.

3.3.5 Drum for holding grains

Drum was made of steel sheet of thickness 16 gauge. The size of the drum was 32 inch (0.81m) length and 18 inch (0.41m) diameter. The drum was able to hold 20 kg of grain (paddy) at a time. Small holes were made of 3mm size at the two sides of the drum to permit air flow through grains. The drum had suitable handles and operating for loading and unloading purposes.

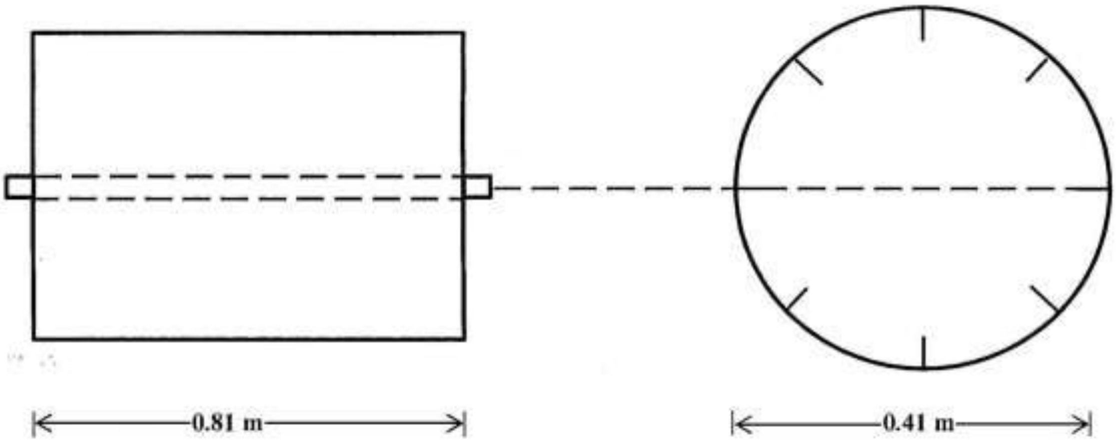

Fig-3.6: Design of the drum used to hold grains for drying

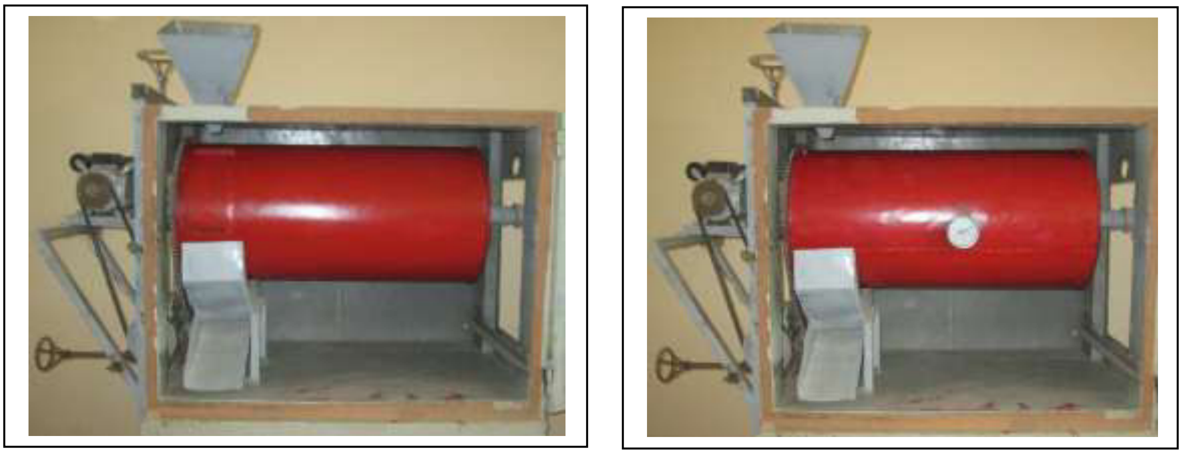

Fig-3.7: Rotary drum of the dryer

3.3.6 Power transmission system

Power transmission is the movement of energy from its place of generation to a location where it is applied to perform useful work. Power is defined formally as units of energy per unit time.

A 0.5 hp, 2 phase, 1420 rpm electric motor was fitted at the side of the frame of the dryer. The power required for rotating the drum was calculated by using the following equations,

Torque was calculated by following equation,

T = I x a

Where,

T = Torque, N-m

I = Moment of inertia, kg-m^2

a = Angular acceleration, rad/sec^2

Moment of inertia for hollow cylinder

$I = MR^2$

Where,

M = Mass, kg

R = Radius of the cylinder, m

Power was calculated by following equation,

$$P = \frac{2\pi nT}{60}$$

Where,

P = Power, hp

T = Torque, N-m

N= revolution per min, (RPM)

Power was transmitted from the prime mover to the drum using V-belt, pulley, chain and pinion. A gear box (30:1) was also used to reduce the RPM of the motor. The size of the pulley was determined by using this formula,

$$D_1 \times N_1 = D_2 \times N_2$$

Where,

D_1= Diameter of small pulley

N_1= RPM of small pulley

D_2= Diameter of large pulley

N_2= RPM of large pulley

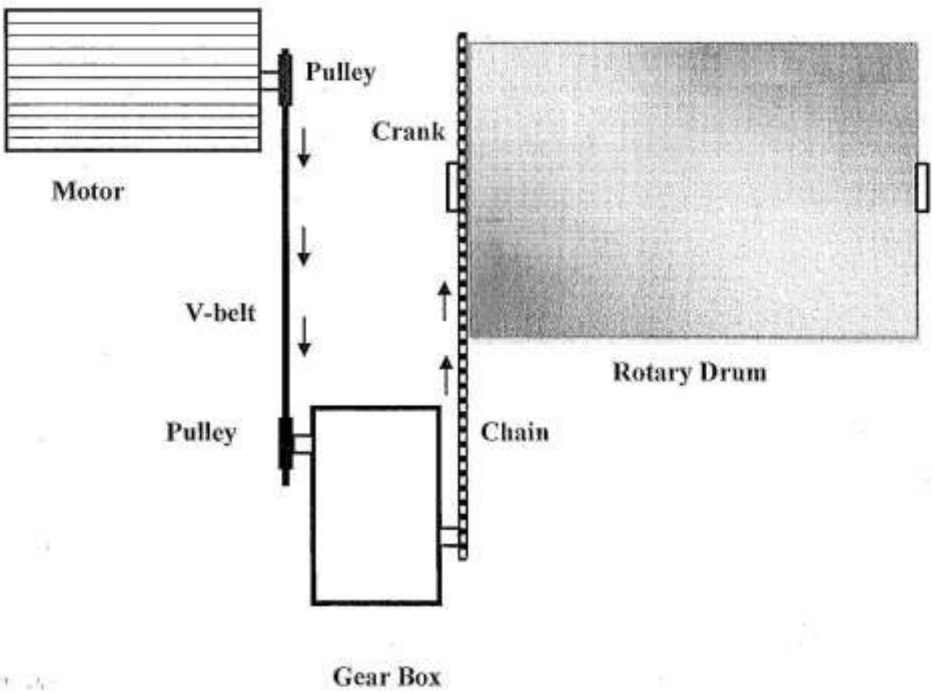

Fig-3.8: Power Transmission System

The length (L) of the belt was calculated from the formula,

$$L = 2C + 1.57(D + d) + \frac{(D - d)^2}{4C}$$

Where,

D is the diameter of big pulley, d is the diameter of small pulley and C is the center distance between the pulleys.

The specification and number of V-belts required to transmit the power was determined using the tables compiled by Faires (1965).

According to (PTD, 1998) the length of the chain was calculated as follows:

$$L = 2C + \frac{N + n}{2} + \frac{(N - n)^2}{4\pi^2 C}$$

Where,

C = centre to centre distance between the two sprockets

N= number of teeth on the larger sprocket

n =number of teeth on the smaller sprocket

3.3.7 Temperature controller

An auto temperature control system was established in this dryer to control safe temperature for grain drying. For this purpose a thermocouple, a temperature controller and a magnetic controller were inter connected with the heater switch and the dryer chamber.

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 had a system by which the required temperature could 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 desired point, the contractor switched off the heater.

3.3.8 Circuit diagram of the control system

From Fig-3.9 it shows that when the deamer 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, the 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 switched off the heaters (fig-3.10).

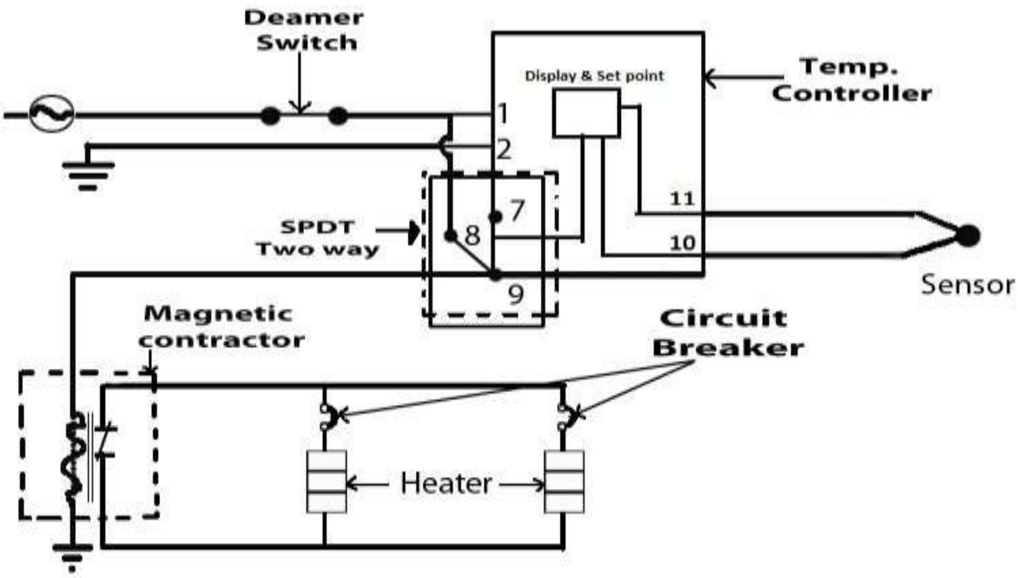

Fig-3.9: Circuit diagram of the auto-control system when heaters on

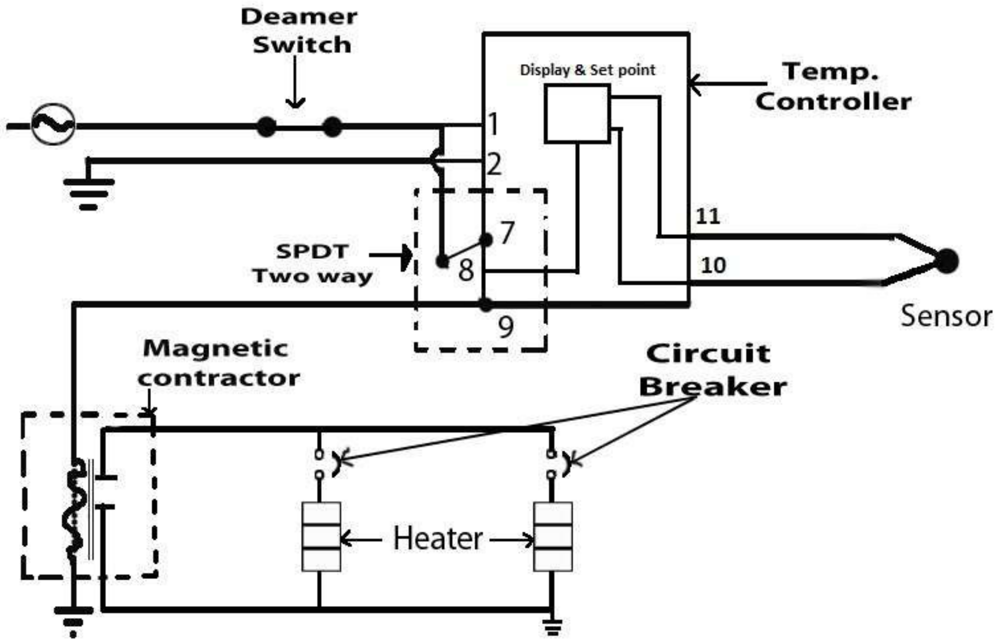

Fig-3.10: Circuit diagram of the auto-control system when heaters off

3.4 Performance of the dryer

3.4.1 Calibration of temperature

To measure the performance of this dryer, 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 was small which might not detect the hot air temperature immediately in comparison to the thermometer sensor which was large.

3.4.2 Measurement of moisture content of seed grains

To study the drying performance of the dryer, freshly harvested, threshed and cleaned paddy was used for drying. 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, 33^0C and 39^0C that gives the drying temperature at 35^0C, 40^{0}C and 45^{0}C respectively, which are the safe temperature for grain seed drying. The blower and the auto-control system were switched on as described above. Moisture content was recorded at 30 minutes interval. To measure the moisture content at certain time, grain sample was collected from the drum for uniform results and used the moisture meter to measure the moisture content.

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.

Fig-3.11: Digital moisture meter

Specification of grain moisture meter

Model	: GMK-303RS
Accuracy	: ±0.5% (below 20%)
Resolution	: 0.1%
Display	: Digital LCD
Operating Temp.	: 5°C ~ +40°C
Power source	: Battery 1.5V x 4EA
Dimensions	: 164(L) x 94(W) x 40(H) mm
Weight	: Approx. 1.5 kg

3.4.2.(a) Experimental design for drying paddy seeds

Several experiments were conducted to study the performance of the dryer. To conduct the experiments three temperature settings inside the rotary dryer respectively 35^0C, 40^0C and 45^0C was used. Quantity of seed grains were also used as 2 kg, 4 kg and 6 kg respectively. The experimental design for seed grain drying is showing in table.

Table -3.1: Experimental design for drying paddy seeds.

Temperature (^{0}C)	Grain quantity (kg)
35	2
	4
	6
40	2
	4
	6
45	2
	4
	6

An experiment was also conducted for drying 4 kg of grain at 45^0C using silicate.

3.4.2 (b) Use of desiccant to remove moisture of grain

Desiccants are drying agents that extract water from a wide range of materials. They are either soluble or insoluble substances that adsorb water due to their chemical properties. Examples include silica gel, bauxite, calcium sulfate and montmorillonite clay. Soluble agents include calcium chloride and glycerol. Molecular sieves, alumina and activated charcoal also make exceptional desiccants. In this experiment, calcium sulfate was used.

Regenerative dryers send air to a molecular sieve (or other) desiccant bed, where the moisture is adsorbed. Later, this moisture is purged by sending heated air through the system; this lowers the moisture retention capabilities of the desiccant and forces it to release stored moisture into the heated air. Eventually, this moisture laden air is expelled and the regenerative dryer cycle is complete.

Fig-3.12: Calcium sulfate ($CaSO_4$)

The use of desiccant to remove moisture of grain seeds was determined by following equation;

Use of desiccant = (Total weight of grain in gmX Initial MC% - Total weight of grain in gmX Final MC%) X 4

3.4.3 Measurement of air flow inside the drum

Air flow was measured inside the drum with the help of vane anemometer. An anemometer is a device used for measuring the speed of wind. A vane anemometer thus combines a propeller and a tail on the same axis to obtain accurate and precise wind speed and direction measurements from the same instrument. The speed of the fan is measured by a rev counter and converted to a wind speed by an electronic chip. Hence, volumetric flow rate may be calculated if the cross-sectional area is known.

Fig-3.13: Vane anemometer

Forty (40) number of readings were taken for wind speed and the average wind speed was found to be 5.88 m/s and the area of the opening was 0.0027m^2(0.09m *0.03m). Air flow was calculated by flowing equation,

$$Q = A \times V$$

Where,

Q=Air flow, m^3/s

A= Area of the opening, m^2

V = Speed of air, m/s

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSIONS

A rotary drum type dryer was designed, constructed and tested in the Agricultural and Industrial Engineering Laboratory of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. Locally available materials were used to fabricate the machine. Surovi Engineering Workshop of Dinajpur Town helped to fabricate the machine. The aim of fabricating the machine was to dry grain and vegetable seeds. The details of the dryer is shown in table-4.1. The total cost of the dryer was Tk. 52,000, the estimated capacity of the dryer was 20 kg grain at a time. The dryer was able to work within the temperature range of 30 to 50^0C.

Table -4.1: Specification of the dryer

Sl No.	Name of the machine parts	Specification
01.	Size of the dryer	1.52 m x 1.04 m
02.	Rotary drum	0.81 m x 0.41 m
03.	Motor	0.5 hp
04.	Blower	420 watt
05.	Electric heater (2)	1400 & 1600 watt
06.	Pulley (2)	6 in (dia.) & 4 in (dia)
07.	V-belt	39 A
08.	Gear box	(30:1)
09.	Drying cost	6.11 Tk/ kg
10.	Cost of dryer	52000 Tk
11.	Capacity of dryer	20 kg

Several experiments were conducted to study the performance of the developed dryer as described below.

.

4.1 Calibration of temperature for temperature controller

Fig-4.1 shows the calibration curve between air temperature inside the dryer and that of the temperature of the controller. The temperature of the dryer was measured by a thermometer installed with the rotary drum. The controller temperature was measured by the thermocouple installed inside the drying chamber.

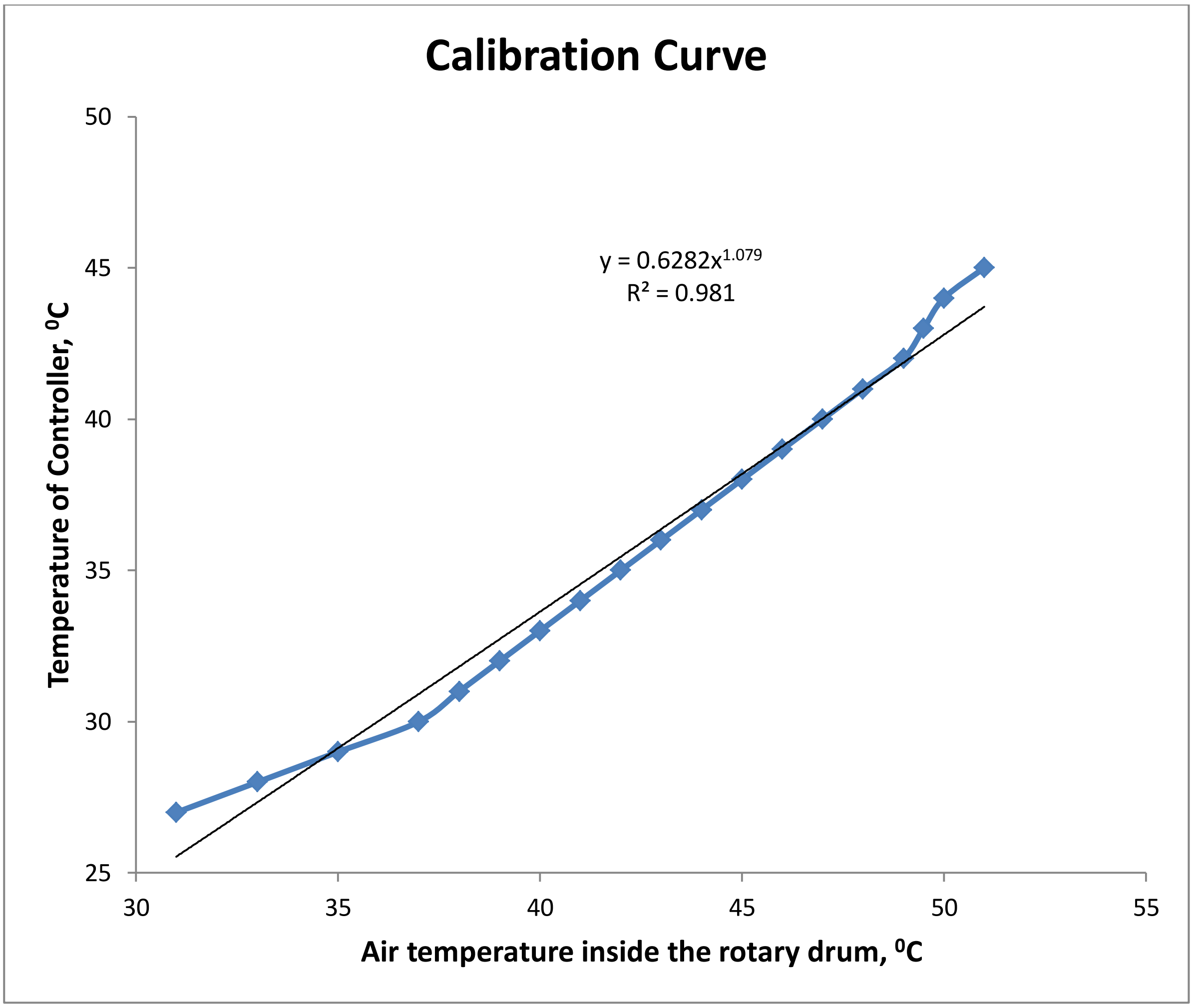

Fig-4.1: Calibration curve

From the calibration curve, the relationship between controller temperature and the dryer temperature could be expressed as

$$y = 0.628\ x^{1.079}$$

where,

x = temperature of the rotary drum

y = temperature of the controller

R^2 = co-efficient of regression

Table-4.2 shows the different temperature of the controller and that of the dryer.

Table 4.2: Temperature calibration for the chamber

Constant	Temperature of rotary drum (^{0}C)	Constant	Temperature of controller (^{0}C)
0.628	x	1.079	$y = 0.628\ x^{1.079}$
0.628	31	1.079	25.535
0.628	33	1.079	27.317
0.628	35	1.079	29.107
0.628	37	1.079	30.906
0.628	38	1.079	31.808
0.628	39	1.079	32.723
0.628	40	1.079	33.619
0.628	41	1.079	34.526
0.628	42	1.079	35.436
0.628	43	1.079	36.347
0.628	44	1.079	37.260
0.628	45	1.079	38.175
0.628	46	1.079	39.091
0.628	47	1.079	40.008
0.628	48	1.079	40.927
0.628	49	1.079	41.848
0.628	49.5	1.079	42.309
0.628	50	1.079	42.771
0.628	51	1.079	43.695

4.2 Experimental results for paddy seed drying

This experiment was conducted to study the performance of the developed dryer. The paddy seeds were dried at 35^0C, 40^0C and 45^0C. In this experiment sample was taken 2 kg, 4 kg and 6 kg. The initial moisture content of paddy seeds was 14.4% and it was dried up to equilibrium moisture content at 35^0C, 40^0C and 45^0C temperature respectively. The paddy was dried for a period of 6 hrs. The variation of moisture content with temperature at 35^0C, 40^0C and 45^0C are shown in fig-4.2, 4.3 and 4.4 respectively.

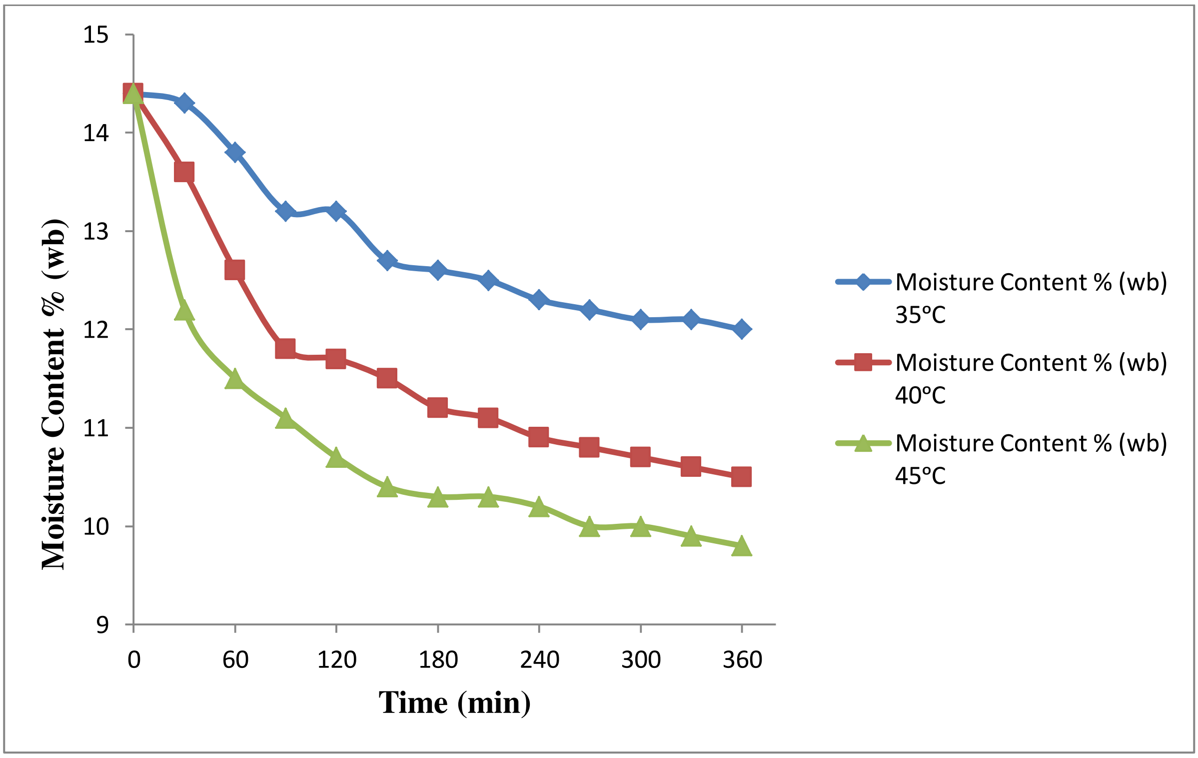

Fig-4.2: Combined drying curve for 2 kg feed rate at different temperatures

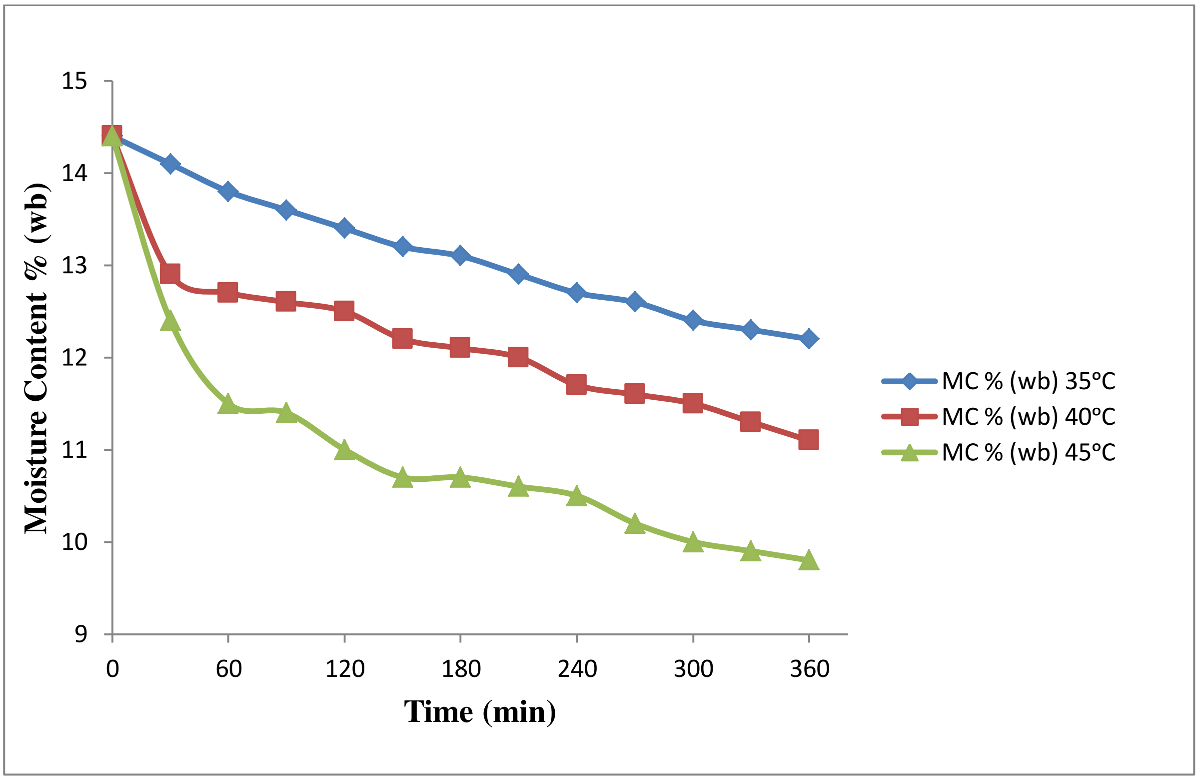

Fig-4.3: Combined drying curve for 4 kg feed rate at different temperatures

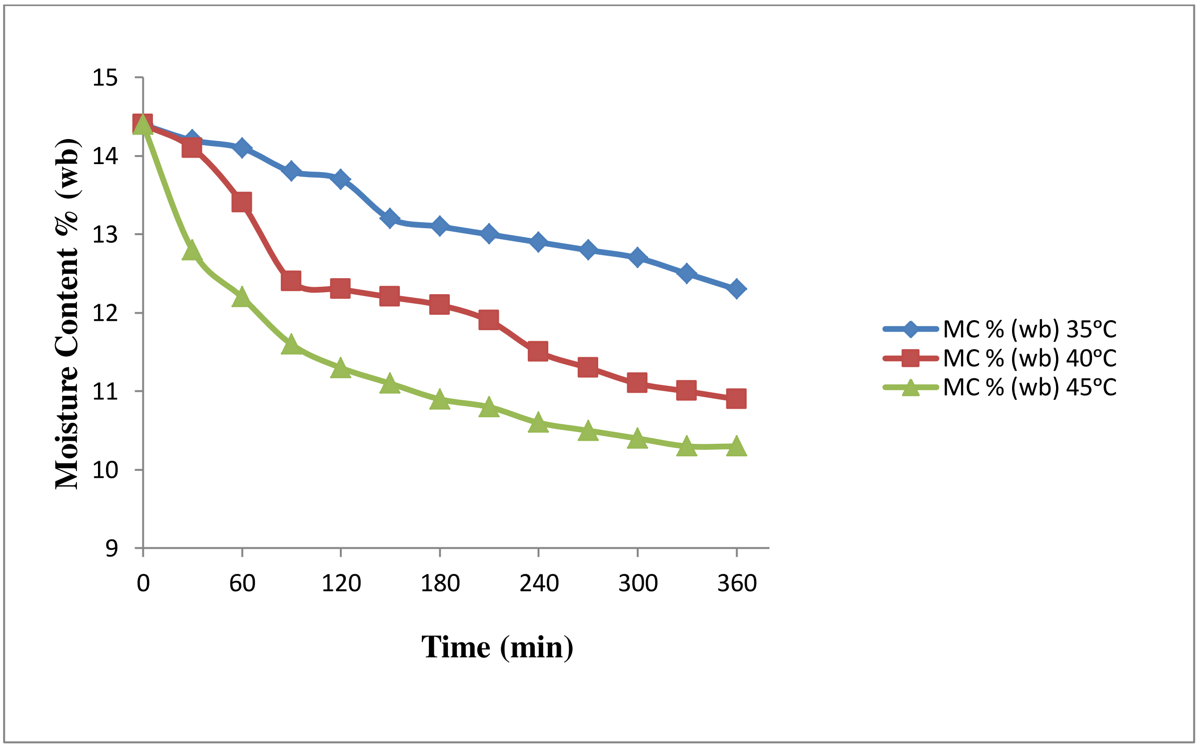

Fig-4.4: Combined drying curve for 6 kg feed rate at different temperatures

The drying curve with time at 30 minutes interval shown in figure 4.2-4.4. After drying in the dryer at 35^0C, 40^0C and 45^0C final moisture content was 12.3%, 10.9% and 9.8% respectively in 6 hours times. From the figure it is shown that when the drying temperature increased then the moisture content of the grain seeds decreased. The highest moisture content was found at 35^0C and lowest moisture content was found at 45^0C drying temperature. It was observed that when wet grain was exposed to hot air, initially there was only a very slight change in moisture content. This happened because all the heat provided in the drying air was used to heat up the grain to the drying air temperature. The experimental results matches with the general phenomena of drying as moisture content of paddy reduces with drying time, Hasan (2010) also found the identical results during drying of rice seed. This findings integrated with the previous study of Midilli et.al (2002) at different temperature and relative humidity.

4.3 Effect of using desiccant in drying seeds

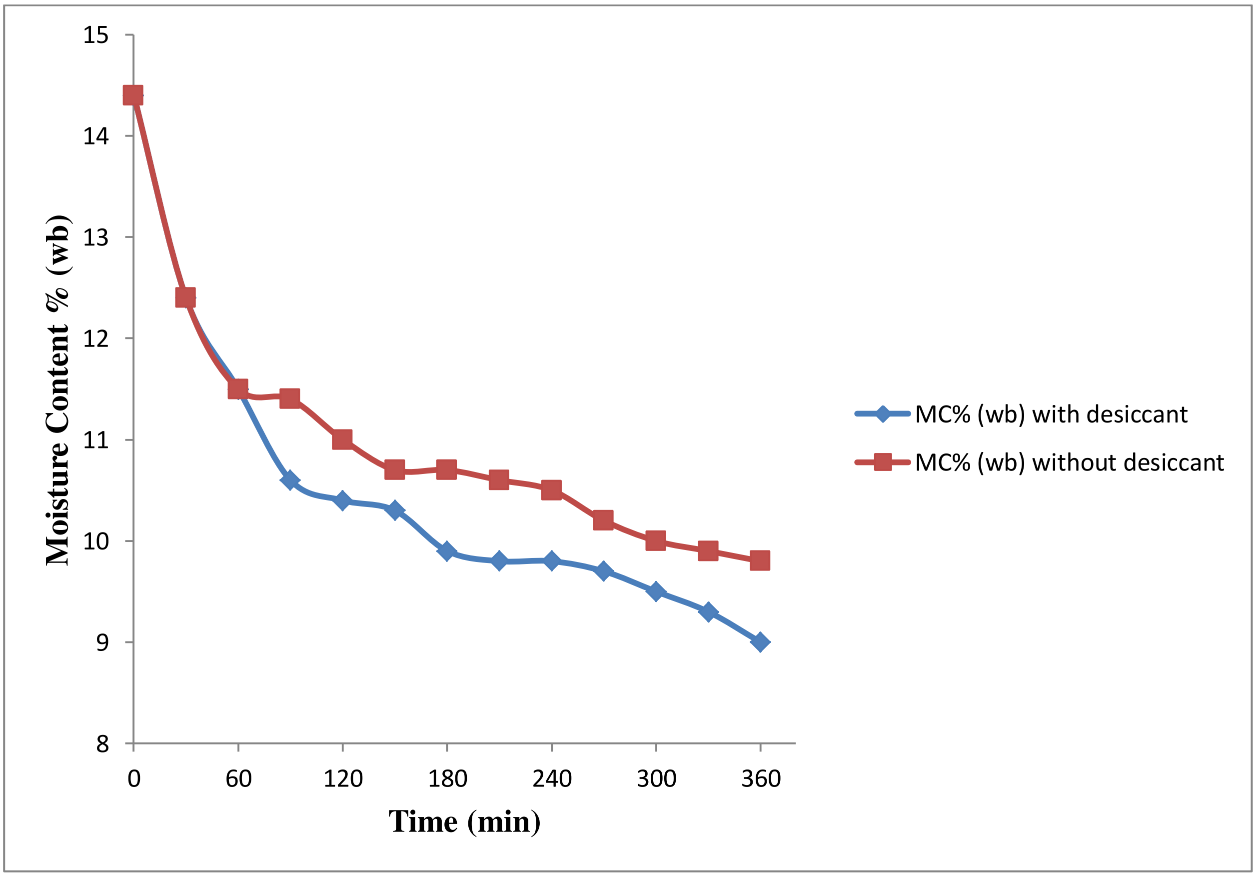

Fig-4.5: Comparison between moisture content with desiccant and without desiccant

Figure-4.5 shown the difference between dried with desiccant (moisture absorbing material) and dried without desiccant. Here it was shown that when desiccant used seed dried more rapidly than without using desiccant. Also at the same time and same temperature, drying is enhanced using desiccant. Desiccants are drying agents that extract water from a wide range of materials.

4.4 Effect of temperature on final moisture content

From the Table-4.3 it is seen that when the temperature increased the final moisture content of the grain decreased simultaneously. The highest final moisture content was found when the sample was dried at 35^0C and lowest final moisture content was found when the sample was dried at 45^0C. There was statistical significant difference between the data, hence temperature had a significance effect on final moisture content.

Table-4.3: Effect of Temperature on final moisture content

Temperature, ^oC	Final Moisture, %
35	12.17^c
40	10.83^b
45	9.93^a

*Means separation in column followed by the same latter(s) are not significantly different at P = 0.05

4.5 Effect of feed rate on final moisture content

From the Table-4.4 it is seen that when the feed rate increased then the final moisture content of the grain also increased. The highest final moisture content was found when the feed rate was 6 kg and lowest final moisture content was found when the feed rate was 2 kg. There was not statistical significant difference between the data, hence feed rate had a significance effect on final moisture content.

Table-4.4: Effect of feed rate on final moisture content

Feed rate,kg	Final Moisture, %
2	10.73^a
4	11.04^b
6	11.16^b

4.6 Combined effect of temperature and feed rate on final moisture content of grain

From the fig.-4.6 it is seen that when the temperature increased final moisture content of the grain decreased and when feed rate decreases the final moisture content of the grain also decreases. The optimum condition of grain drying in this seed dryer could be found from the requirement of the user demand. But there was not significance difference of moisture content among 2 kg, 4 kg and 6 kg feed rate.

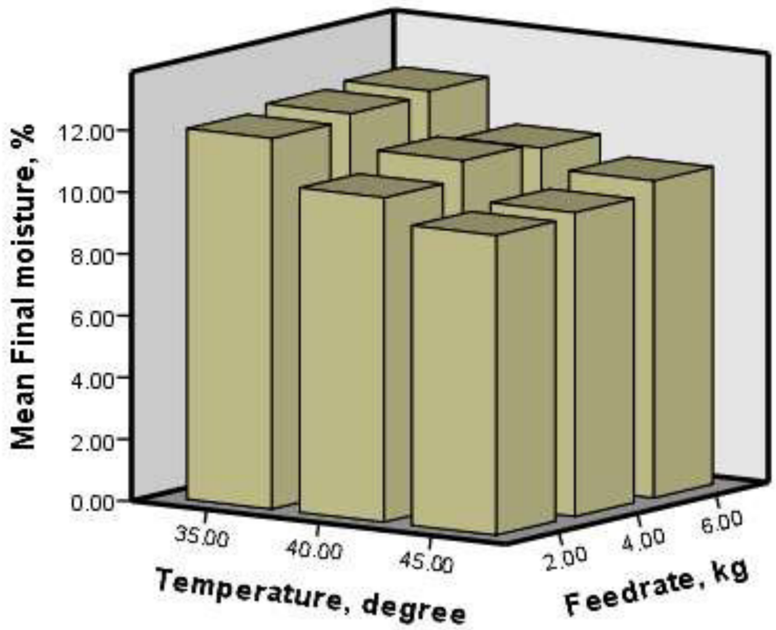

Fig-4.6: Combined effect of temperature and feed rate on final moisture content of grain

4.7 Effects of drying temperature on drying time

Analysis of the data showed that drying time was significantly affected by the drying air temperature. It is noticed from fig-4.7 that at lower temperature (35^{o}C) drying time was higher and at higher temperature (45^{o}C) drying time was lower for low moisture seed paddy drying in the rotary dryer. At higher air temperature, sensible heat of grain is more which enhance the evaporation of moisture from the grain. In addition, at higher temperature relative humidity of drying air decreases within control volume of drying chamber. Therefore, capacity of moisture absorption increases that evaporate from the grain.

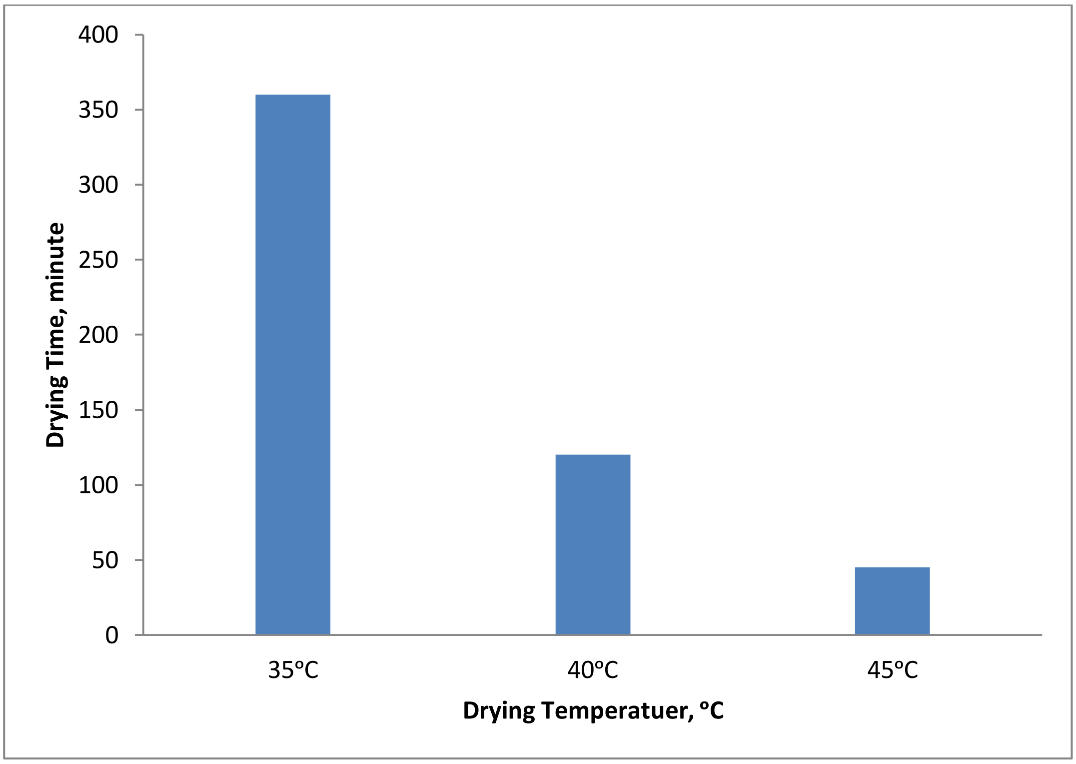

Fig-4.7: Effects of drying temperature on drying time

4.8 Estimation of cost of drying

Economic analysis for drying of paddy seeds in rotary type grain seed dryer is given in Table-4.5. From the table, it could be seen that the cost of drying is Tk. 106.96 per hr.

Table-4.5: Cost calculation of drying of paddy seeds in rotary type grain dryer

Cost components	Unit	Amount
A. Cost of the dryer	**Tk/Unit**	
1) Construction cost	Tk	52000
B. Life of dryer	Year	10
C. Annual use	Hrs	400
D. Fixed cost		
1) Depreciation	Tk /yr	4680
2) Interest (13%)	Tk /yr	3718
3) Taxes, shelter, insurance (3%)	Tk /yr	1560
Total	Tk /yr	9958
Total fixed cost	Tk/hr	24.89
E. Variable cost		
1) Labour (one labour 400 Tk/day)	Tk/hr	50
2) Repair and maintenance cost (10%)	Tk/hr	13
3) Cost of electricity (assuming price of electricity 5.37 Tk/unit)	Tk/hr	20.37
Total variable cost	Tk/hr	83.37
F. Total cost (D+E)	Tk/hr	108.26

The drying cost of Tk. 32.47/kg seems to be expensive particularly for paddy drying. But if we consider for other expensive vegetable seeds, this cost is not very high comprised to their market price (several thousand take per kg). Also as a single dryer unit, at the fabrication cost was high. The majority portion of the cost goes to the cost of labour and that of electricity. Where the fixed cost is only Tk. 24.89/hr, the variable cost is Tk. 83.37/hr (including labour cost and power cost)

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

A small scale grain seed dryer was developed for drying grain seed using locally available materials. A rotary drum was incorporated for increasing the performance of the dryer and reducing operating cost. The total cost of the dryer including fabrication was Tk 52,000. The total size of the dryer was 1.52 m height and 1.04 m wide. Two insulated electric heaters of 1400 watt and 1600 watt capacity was used for heating air and a blower 420 watt was used to blow air through the heater towards the dryer. The temperature of the dryer controlled by the control system which maintains the safe level of the grain seed drying temperature between dryer chamber and the controller. Different sizes of steel piping were used to convey the hot air to the dryer chamber. A 0.5 hp motor was used for rotating the drum. The rotary drum stirred the grain seed and dried uniformly. The prime mover was attached to the drum using V-belt, pulley, chain and pinion. A gear box (30:1) was also used to reducing the RPM of the motor. Grain samples (paddy) of 2 kg, 4 kg and 6 kg were dried in the dryer at temperatures 35^0C, 40^0C and 45^0C respectively. The initial moisture content of the grain as determined by using an oven dryer in bone dry method was 14.4%. Moisture contents after drying in the dryer at 35^0C, 40^0C and 45^0C was 12.3%, 10.9% and 9.8% respectively in 6 hours times. Also use of desiccant the moisture content was 9.0%. The total cost of drying per kg of seed was Tk. 32.47.

Certain modifications are required in the dryer for better use and better performance. The grain loading and unloading method need to be improved. The insulation of the chamber need to be improved to protect heat loss. Power transmission elements need to be relaxed and improved. All the units need to be assembled in a single complete unit and market user friendly.

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APPENDICES

APPENDICES

Appendix I

Temperature difference between the dryer chambers and controller.

Time (min)	Temperature (^0C)		
	Rotary drum	Controler	Difference
0	31	27	4
1	33	28	5
2	35	29	6
3	37	30	7
4	38	31	7
4.5	39	32	7
5	40	33	7
5.5	41	34	7
6	42	35	7
7	43	36	7
7.5	44	37	7
8	45	38	7
9	46	39	7
10	47	40	7
11	48	41	7
12	49	42	7
13	49.5	43	6.5
14	50	44	6
15	51	45	6

Appendix II

Determination of pulley size

For power transmission motor to gearbox,

Assume, D_1= 4 inch

N_1= 1420 rpm

N_2= 947

D_2= ?

Therefor

$D_1 \times N_1 = D_2 \times N_2$

$$\therefore D_2 = \frac{D_1 \times N_1}{N_2}$$

$$= \frac{4 \times 1420}{947}$$

= 5.99 inch

$\approx$ 6 inch

$\therefore$ D_1= 4 inch

D_2 = 6 inch

Appendix III

Calculation of power required for rotary drum

We have,

Weight of the drum, M = 100 kg (by metal weight calculator)

Radius of the drum, R = 0.205 m

Therefore

Moment of inertia of the drum, $I = MR^2$

$$= 100 \times 0.205^2$$

$$= 4.20.\text{kg-m}^2$$

Angular acceleration, $\alpha = \frac{\omega}{t} = \frac{2\pi n}{t}$

$$= \frac{2\times\pi\times16}{60\times1} = 1.67 \ \text{rad/sec}^2$$

Torque, $T = I\alpha = 4.20 \times 1.67 = 7.014$ N-m

Actual power required,

$$P = \frac{2\pi nT}{60} = \frac{2 \text{ x } 3.1416\times16\times7.014}{60}$$

$$= 11.75 \text{ watt}$$

= 0.015 hp

Transmission efficiency = 80%

Total power = 0.015/0.8

= 0.018 hp

Appendix IV

Determination of type and pitch length of the belt

We have,

Driver machine: Single phase electric motor

Hp= 0.5; N_1= 1420 rpm

Driven Machine: Dryer

Hp= 0.38; N_2= 14 rpm

∴ Transmitted horsepower, hp = 0.38

From appendix V,

N_{sf} = 1.4-0.2 = 1.2 (for machine tools, seasonal use)

∴ Design hp $= N_{sf} \times transmitted\ h$

$$= 1.2 \times 0.38 = 0.46\ hp$$

For hp = 0.46 and N= 1420 rpm from appendix VI,

We get A-type belt

Now, for power transmission from motor to gear box

D= 6 inch; d= 4 inch

Center distance between the pulley, C= 13 inch

$$\therefore \text{Now } L = 2C + 1.57(D + d) + \frac{(D-d)^2}{4C}$$

$$L = 2 \times 13 + 1.57 \times (6 + 4) + \frac{(6-4)^2}{4 \times 13}$$

$$= 41.77 \text{ inch}$$

From appendix VII,

For L = 41.77 inch & A type we choose A-39 number belt

Again, for power transmission from gearbox to drying unit

For 5 rpm,

C = centre to centre distance between the two sprockets = 11 inch

N= number of teeth on the larger sprocket = 90

n =number of teeth on the smaller sprocket =10

$$L = 2C + \frac{N+n}{2} + \frac{(N-n)^2}{4\pi^2 C}$$

$$L = 2\times 11 + \frac{90+10}{2} + \frac{(90-10)^2}{4\times \pi^2 \times 11}$$

= 86 inch

Therefore, length of the chain 86 inch

Appendix V

Service Factor N_{sf}

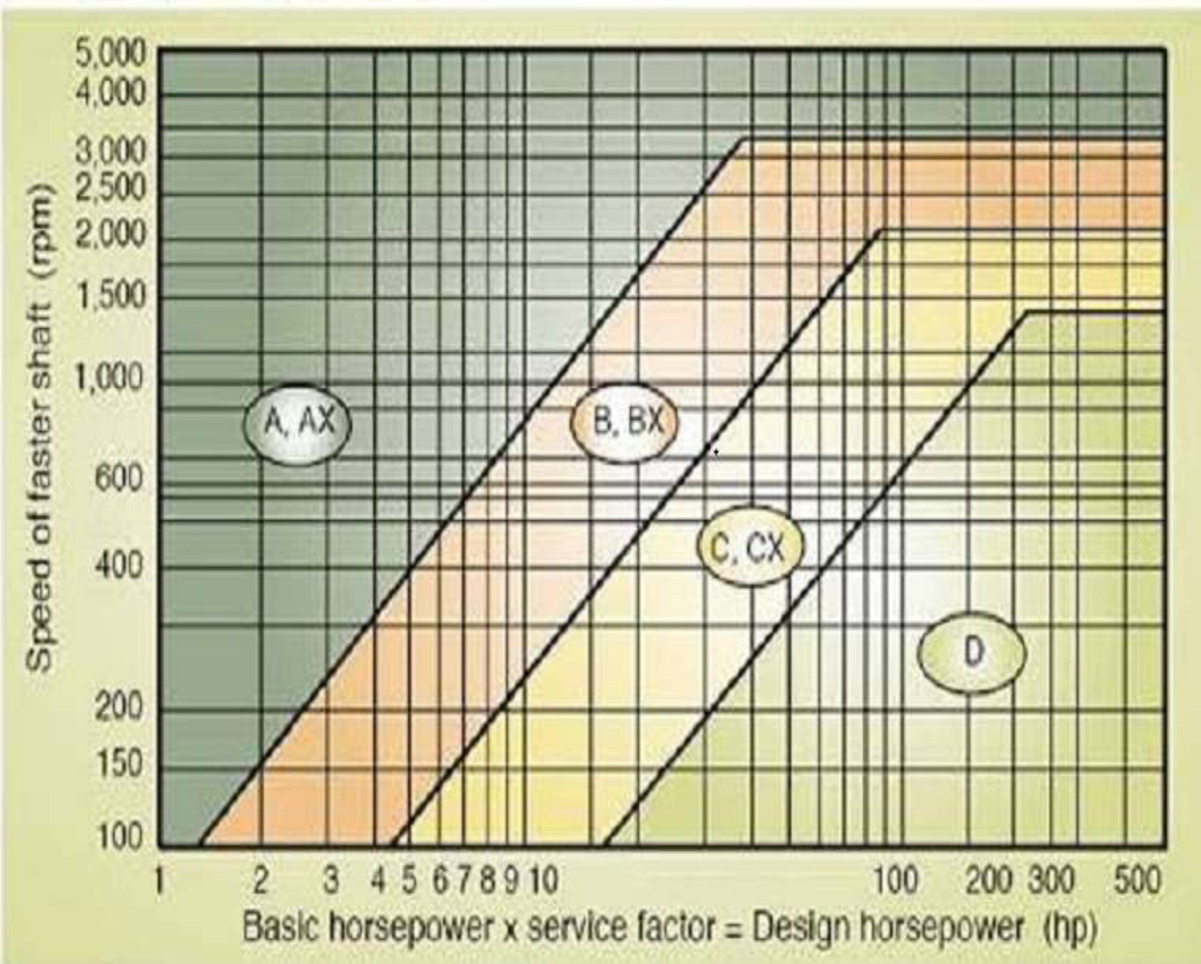
Add 0.2 to the values given for each of the following condition: continuous (over 16 hr/day) service; wet environment; idler in drives. Subtract 0.2 if the operation is quite intermittent or seasonal.

Driven Machines	Driving Machines	
	Electric Motors AC split phase AC Normal Torque Squirrel cage, and Synchronous DC Shunt Wound Water wheels Turbines, Steam and Water Internal Combustion Engines (Hydraulic Drive)	Electric Motors AC Single Phase SeriesWound AC High Torque or High Slip AC Slip Ring AC Repulsion Induction AC Capacitor DC Compound wound Steam Engines and Line Shafts Clutch on Driver or Driven Shaft
Agitators, liquid Cam cutters Conveyors, Package Drill presses, Lathes Screw machines Small fans to 10 hp	1.1	1.2
Compressors and blowers, (rotating) Conveyors, ore, sand generators Line shafts Machine Tools (other) Pumps (Rotating)	1.2	1.4
Ball mills Beaters (paper) Circular saws Compressors (reciprocating) Conveyors, bucket, apron, screw, drag Crushers, jaw, etc. Hammer mills Pumps (reciprocating) Propellers Tube mills	1.4	1.6
Hoists Mine fans Positive blowers Spinning frames Tumbling barrels Twisters (textile)	1.6	1.8

(Source: Design of Machine Element, V. M. Faires, Fourth Edition)

Appendix VI

Selection of Belt Section from Horsepower and Speed



(Source: Design of Machine Element, V. M. Faires, Fourth Edition)

Appendix VII

Standard V-Belt Lengths; Horsepower Constants

Minimum D_s is the smallest sheave pitch diameter that should be used with that section. A smaller sheave is used, short belt life should be expected; L in inches.

A SECTION		B SECTION		C SECTION		D SECTION	
Min Ds = 3 in		Min Ds = 5.4 in		Min Ds = 9 in		Min Ds = 13 in	
Belt No.	Pitch Length	Belt No.	Pitch Length	Belt No.	Pitch Length	Belt No.	Pitch Length
A 26	27.3	B 35	36.8	C 51	53.9	D 120	123.3
A 31	32.3	B 38	39.8	C 60	62.9	D 128	131.3
A 35	36.3	B 42	43.8	C 68	70.9	D 144	147.3
A 38	39.3	B 46	47.8	C 75	77.9	D 158	161.3
A 42	43.3	B 51	52.8	C 81	83.9	D 173	176.3
A 46	47.3	B 55	56.8	C 85	87.9	D 180	183.3
A 51	52.3	B 60	61.8	C 90	92.9	D 195	198.3
A 55	56.3	B 68	69.8	C 96	98.9	D 210	213.3
A 60	61.3	B 75	76.8	C 105	107.9	D 240	240.8
A 68	69.3	B 81	82.8	C 112	114.9	D 270	270.8
A 75	76.3	B 85	86.8	C 120	122.9	D 300	300.8
A 80	81.3	B 90	91.8	C 128	130.9	D 330	330.8
A 85	86.3	B 97	98.8	C 144	146.9	D 360	360.8
A 90	91.3	B 105	106.8	C 158	160.9	D 390	390.8
A 96	97.3	B 112	113.8	C 173	175.9	D 420	420.8
A 105	106.3	B 120	121.8	C 180	182.9	D 480	480.8
A 112	113.3	B 128	129.8	C 195	197.9	D 540	540.8
A 120	121.3	B 144	145.8	C 210	212.9	D 600	600.8
A 128	129.3	B 158	159.8	C 240	240.9	D 660	660.8
		B 173	174.8	C 270	270.9		
		B 180	181.8	C 300	300.9		
		B 195	196.8	C 330	330.9		
		B 210	211.8	C 360	360.9		
		B 240	240.3	C 390	390.9		
		B 270	270.3	C 420	420.9		
		B 300	300.3				
Rated hp. Constants				Rated hp. Constants		Rated hp. Constants	
a = 2.684				a = 8.792		a = 18.788	
c = 5.326				c = 38.819		c = 137.7	
e = 0.0136				e = 0.0416		e = 0.0848	

(Source: Design of Machine Element, V. M. Faires, Fourth Edition)

Appendix VIII

Drying cost calculation

Power requirement of motor = 0.5 hp x 6 hr

= (0.5 x 746) watt x 6 hr

= 2238 watt hr

= 2.24 KW hr = 2.24 unit

Power requirement of blower = 420 watt x 6 hr

= 2520 watt hr

= 2.52 KW hr = 2.52 unit

Power requirement of both heater = (1400 + 1600) watt x 6 hr

= 18000 watt hr

= 18 KW hr = 18 unit

Total power required = (2.24 + 2.52 + 18) unit = 22.76 unit

Assuming the price of electricity = TK 5.37 / unit

Total cost = 5.37 x 22.76 = Tk 122.22

We can drying at a time 20 kg seed. So drying cost 6.11 Tk/ kg. (only power use cost)

Cost of drying = Tk.108.26/hr

= 108.26 Tk/hr x 6 hr/wt of 20 kg seed

= 649.56/20 kg of seed

= 32.47 Tk/kg

Appendix IX

Dryer evaluation data

 # Drying at 35^{0}C

Time (min)	Moisture Content % (wb) 2Kg	Moisture Content % (wb) 4Kg	Moisture Content % (wb) 6Kg
0	14.4	14.4	14.4
30	14.3	14.1	14.2
60	13.8	13.8	14.1
90	13.2	13.6	13.8
120	13.2	13.4	13.7
150	12.7	13.2	13.2
180	12.6	13.1	13.1
210	12.5	12.9	13
240	12.3	12.7	12.9
270	12.2	12.6	12.8
300	12.1	12.4	12.7
330	12.1	12.3	12.5
360	12	12.2	12.3

 # Drying at 40^{0}C

Time (min)	Moisture Content % (wb) 2Kg	Moisture Content % (wb) 4Kg	Moisture Content % (wb) 6Kg
0	14.4	14.4	14.4
30	13.6	12.9	14.1
60	12.6	12.7	13.4
90	11.8	12.6	12.4
120	11.7	12.5	12.3
150	11.5	12.2	12.2
180	11.2	12.1	12.1
210	11.1	12	11.9
240	10.9	11.7	11.5
270	10.8	11.6	11.3
300	10.7	11.5	11.1
330	10.6	11.3	11
360	10.5	11.1	10.9

Drying at 45^{0}C

Time (min)	Moisture Content % (wb) 2Kg	Moisture Content % (wb) 4Kg	Moisture Content % (wb) 6Kg
0	14.4	14.4	14.4
30	12.2	12.4	12.8
60	11.5	11.5	12.2
90	11.1	11.4	11.6
120	10.7	11	11.3
150	10.4	10.7	11.1
180	10.3	10.7	10.9
210	10.3	10.6	10.8
240	10.2	10.5	10.6
270	10	10.2	10.5
300	10	10	10.4
330	9.9	9.9	10.3
360	9.8	9.8	10.3

At 45^{0}C with 4 kg using desiccant

Time (min)	MC% (wb) with desiccant	MC% (wb) without desiccant
0	14.4	14.4
30	12.4	12.4
60	11.5	11.5
90	10.6	11.4
120	10.4	11
150	10.3	10.7
180	9.9	10.7
210	9.8	10.6
240	9.8	10.5
270	9.7	10.2
300	9.5	10
330	9.3	9.9
360	9	9.8