Performance Investigation of a Natural Convection Grain Dryer for Paddy Drying

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Abstract- Providing food security to all the people around the world is a challenging task in the current scenario. Improving the method of food preservation and minimizing the grain loss is required for achieving the food security. Rice is considered to be the major staple food all over India. Proper drying and removing moisture from paddy can increase the availability of rice to all the people across India. The present work focuses on developing a natural convection grain dryer for the coastal climate of Odisha, India. The natural convection dryer being developed uses the heat energy from the combustion of coal to heat air. The hot dry air is passed over paddy for drying. In this dryer, variation of drying air temperature and amount of biomass required for proper drying of different amounts of paddy being dried are analysed. Finally the moisture removal rate from paddy for different weight (10 to 25 kg) and different relative humidity is studied.It was found that with increase in thickness of paddy (~2.5 to~5.5 cm), the drying time increases and initial surface moisture transfer decreases. It was also found that initial moisture transfer is more in case 10 kg of paddy as surface area of exposure is more with less amount of paddy in batch drying process. Finally paddy drying is done in batch wise and continuous process. It was found amount of biomass required in continuous drying is less than that of batch drying. Particularly Pongamiapinnata type of wood is used in the furnace for generating the thermal energy.

Keywords Paddy, natural convection dryer, biomass, moisture removal rate

1. Introduction

India is the second largest rice producer in the world [1]. It is also reported that around 56,000 tonnes of food grain, including 27,000 tonnes of rice, were damaged since 2010 in India [2]. Inadequacy of proper drying methods is the major reason for such huge amount of food loss. Proper drying involves reducing the moisture content of the paddy grains to acceptable levels. Moisture content of 14% (wb) is the proper moisture content for storing and preserving paddy grains.

There are several methods for drying paddy. One of the common methods used in India for drying paddy post harvesting is open sun drying. This traditional method of drying has many drawbacks like improper drying of food grains, food contamination by dust and insects, loss of food by birds and rodents etc. Also open sun drying method can be utilized only during the day time on sunny days only. To overcome these limitations of open sun drying natural and forced convection drying are two potential options [3]. Forced convection drying requires a blower for movement of drying air and a heating system for heating drying air. This requires electricity. Availability of electricity in the rural areas of India is difficult. The use of electrical heating systems and fans are not popular for drying of agricultural products [4]. The use of electrical energy for drying also increases the cost of food grains. Hence as compared to forced convection drying, natural convection drying is more popular in the rural areas of developing countries for grain drying [5].

There have been many attempts to develop natural convection dryers. Bassey et al. [6] used a saw dust burner to assist solar dryer during night time and rainy days. 400 W/m^2 of energy was supplied to the drying cabinet using the burner, with steam being the heat transfer medium. Akyurt et al. [7] developed an indirect type solar heater with a biomass burner as back up. They found that the drying time decreased by the use of back up burner. Bena et al. [8] designed and developed a direct solar dryer and included biomass-backup heater. The thermal performance of the system was satisfactory. El-Sebaii et al. [9] designed, constructed and investigated an indirect type natural convection solar dryer experimentally under Tanta prevailing weather conditions. They reported that the equilibrium moisture content (M_e) for seedless grapes is reached after 60 h when the system is used storage material and 72 hour without storage material. Therefore the storage material reduces the drying process by 12 hour.Prasad and Vijay [10] fabricated an integral type natural convection solar drier coupled with a biomass stove. It was found that drying time has been reduced to 54–60 hour and 83–84% in solar-biomass hybrid drier in comparison to ‘only solar’ and open sun drying operation. Amer et al. [11] designed and constructed a hybrid solar dryer by using direct solar energy and a heat exchanger. They found the efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer.Koyuncu[12] designed, constructed and tested two different types of natural-circulation greenhouse crop dryers. He reported that the use of natural circulation greenhouse dryers for drying agricultural products was 2.5 times more efficient than open air drying. He also reported that use of black coated solar radiation absorber surface and chimney improves the performance of these dryers. The present investigation focuses on development of a natural convection type complete biomass dryer for the drying need of the rural people of developing countries like India.

Many of the research work on drying are based on solar radiation drying. Very few works has been conducted on drying of paddy using biomass. Particularly no work has been conducted on drying of paddy using biomass energy in natural convection mode of heating for climatic condition of India. Biomass energy can be very helpful in drying particularly at night time, also in rainy seasons.

2. Designand Developmentof Experimentalset up

The biomass burner is designed primarily for the fuel wood. An indirect heating system was used and precaution was taken to avoid the mixing of flue gases from the chimney and the drying air to avoid food contamination. A conical shape biomass furnace (as shown in figure 1) having bottom diameter of 60 cm and top diameter of 30 cm is constructed using mild steel.An exhaust pipe of galvanized iron of diameter 6.35 cm and length of 2 m is connected through it horizontally. Conical furnace is chosen to provide natural draught for the flue gases of combustion. The flue gas exhaustion takes place through a 1.8 m length and 6.35 cm diameter mild steel pipe connected vertically. The conical furnace is kept on a rectangular stand (base) of 61 cm× 61 cm× 22 cm covered from three sides as shown in figure 2. Only the front side of the rectangular stand is open. There is a fix projection of 30 cm to the outside from the front of the rectangular stand. A moveable ash tray of 60 cm×60 cm×2 cm is placed on the projection for the removal of ash after burning of biomass. The biomass burns on a perforated plate having dimension 59 cm×59 cm, which is kept on the top part of the stand. A cover plate is used to cover the projection of 30 cm. The conical furnace, rectangular stand, ash tray, cover plate and biomass burning plate can be easily disassembled for maintenance. For the feeding of biomass from the outside of the wall into the conical furnace, an inclined thin circular pipe is used. One end of the pipe of diameter 20 cm is connected to the conical furnace. The other end of diameter 13.5 cm is kept on the small opening of the wall. A brick chamber of dimension 1.22 m×0.95 m×0.9 m encloses the biomass burner was constructed. There were eight rectangular holes on the brick wall perimeter at ground level for fresh air entry. Out of the eight rectangular holes, six are along the length and two are along the width of brick wall. The top view of the natural convection biomass dryer along with the drying of paddy in a batch drying process is represented in figure 3. The drying is done on a wire meshed drying tray which provides an effective drying area of ~1m^2.

Figure 1. Furnace of the biomass dryer with exhaust pipe.

Figure 2. Base of the biomass dryer with ash tray and biomass burning tray.

Figure 3. Top view of the Biomass dryer and paddy drying on the dryer.

3. Experimental Procedureand Instrumentation

The dryer used for this study is designed to make use of biomass energy. Drying parameters were observed at five different points i.e. at centre and four corners of the tray. When biomass burns, the surface of the conical furnace gets heated up which in turn warms the surrounding air. The heated air rises up by natural convection, passing through the drying trays and picking up the moisture. This action reduces the pressure inside the dryer and the ambient air is drawn into the dryer through the inlet of holes at the bottom of the brick chamber. A continuous flow of air is thus established. The temperature inside the dryer is controlled by controlling the feeding rate of the fuel wood in the biomass burner. The novelty of the dryer is that it can be operated by even an unskilled labourer.

The following parameters were measured during the experiments:(a)mass of paddy before and after drying (b) amount biomass burnt (c) temperature at different points (d) level of moisture content. Thermocouples of K-type are used for measurement of temperature. Thermocouples are calibrated before being used in experiments. Electronic balance (Make: Shimadzu, Japan)is used for weight measurement of biomass and sample of paddy. For moisture measurement a handy data logging moisture meter (make: Indosaw) is used. The paddy samples have been taken from 5 different places to obtain the uniformity.

Relative humidity of air was measured by hygrometer (Model: THM-B_2).A bomb calorimeter was used for measuring the calorific value of wood.

4. Resultand Discussion

Variation of drying air temperature

Drying air temperature depends on the amount of biomass burnt and the rate of burning. Since variation of drying air temperature affects the moisture transfer and the quality of paddy, it is necessary to plot the variation of drying air temperature just below the paddy tray. The average value of the variation of drying air temperature just below the paddy tray with time are shown in figure 4 (a), (b), (c), and (d) for paddy amount 10kg, 15kg, 20kg, 25kg respectively. When the temperature of drying air reaches above 45^{0}C, paddy is loaded on the drying tray for quality drying. Drying air temperature is controlled by controlling the feeding rate of biomass and air supply to the furnace. When temperature of drying air falls nearer to 45^{0}C, the biomass is supplied to the furnace so that temperature again rises above 45^{0}C. For better quality of drying of the product, paddy should be dried between 50^{0}C to 65^{0}C. Drying air temperature is measured at five different points just below the drying tray and then the average value of the five temperatures is considered. The variation of drying air temperature below the paddy tray at five different positions at particular time is very small. But the average drying air temperature variation during the drying of different quantity of paddy is very large.

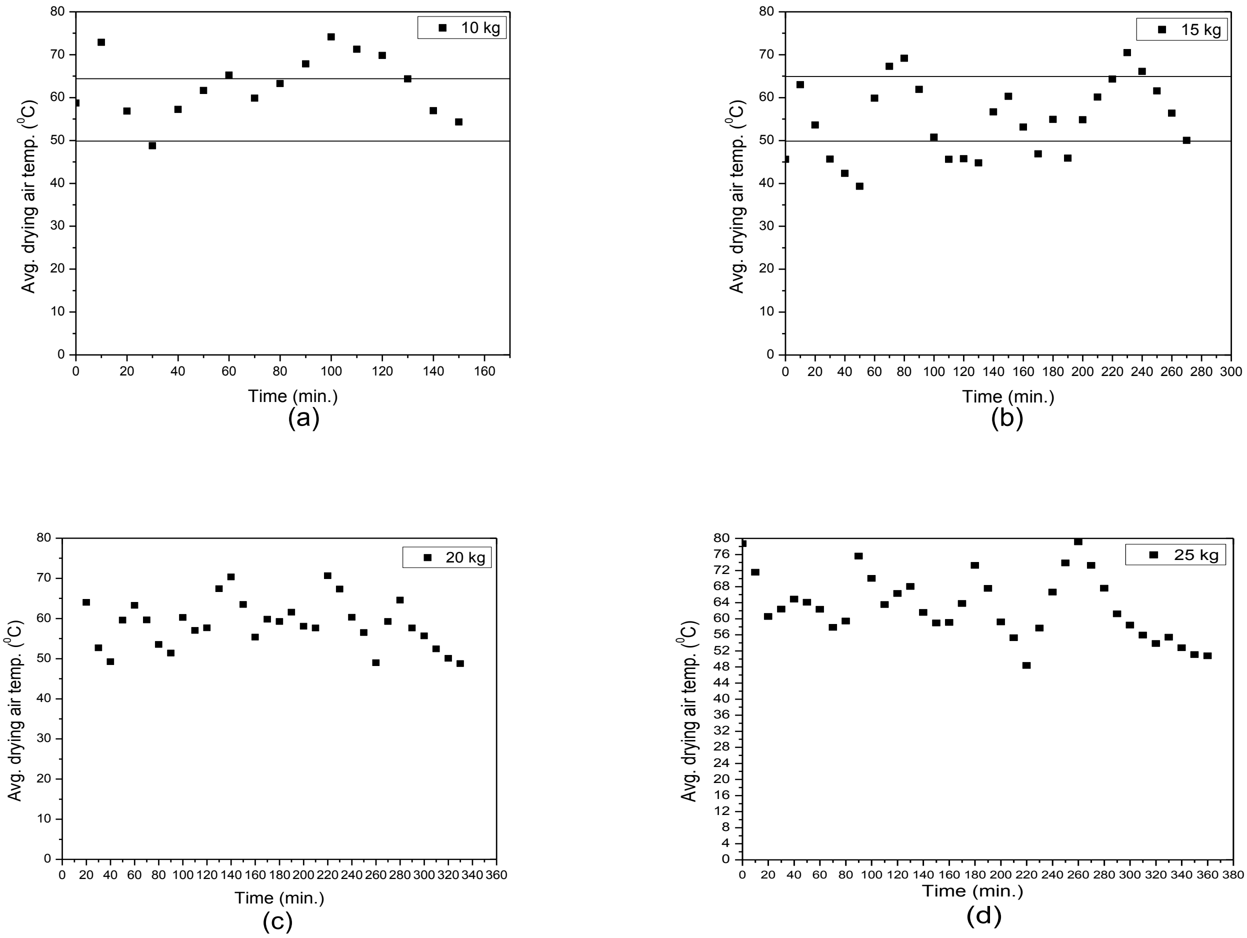

Figure 4. Variation of drying air temperature for different masses of paddy (figure (a), (b), (c) and(d) for 10 kg, 15 kg, 20 kg and 25 kg respectively) with drying time during the experiment.

Capacity and drying time

Four batches of paddy of different amount (in weight) and having different thickness on the drying tray are dried in two processes by using the different amount of biomass.

- Process-1: Drying of different amounts of paddy at different times of different days.
- Process-2: Drying of different amounts of paddy continuously just one after another batch.

It was observed that the biomass required for different batches of paddy in the first process is higher than the second process. Because in the first method at one time only one batch of paddy is dried, so lot of heat energy is wasted after unloading of dried paddy. Again to dry another batch of paddy firing of biomass is required to attain the same drying air temperature. So there is waste of fuel, energy and time to dry the paddy. But in case of continuous drying when one batch of paddy was unloaded another batch of paddy was loaded immediately.Hence there was no need to raise the temperature of drying air. So there is saving of fuel, energy and drying time.

Table 1. Details of experimental results for drying of one batch of paddy

Sl.no.	Amount of paddy (kg)	Thickness of Paddy (cm)	Amount of moisture removal (%)	Avg. Atm. Humidity (%)	Time taken for moisture removal (hr)	Amount of biomass required (kg)
1	10	~2.5	15.94	66	2.7	1.9
2	15	~3.5	15.85	67	4.3	2.8
3	20	~4.5	15.91	63	5.2	4.1
4	25	~5.5	15.89	64	5.8	5.2

For drying of paddy in process-1, two different amounts of paddy are taken for the performance analysis. Three batches of paddy of 10kg each (total 30 kg) are taken at different time of the different days and dried at the same relative humidity. Similarly two batches of paddy of 15kg each(total 30kg) are taken at different time of the different days. Paddies are dried at same relative humidity to compare the result. Again two batches of 20 kg paddy are also taken in process-1 and process-2 to compare the performance.

Table 2. Details of experimental results for drying of three batches of paddy inthe process-1

Sl.no	Amount of paddy in one batch(kg)	Total amount of paddy dried (kg)	Amount of moisture removal (%)	Avg. Atm. Humidity (%)	Time taken for moisture removal (hr)	Amount of biomass required (kg)
1	10	30kg	15.9,15.8,15.8	65	8.1	5.7
2	15	30kg	15.7,16.1	65	8.6	5.6
3	20	40kg	16.0,15.8	65	10.4	8.2

For drying of paddy in process-2, two different amounts of paddy are taken for the performance analysis. Three batches of paddy of 10kg (total 30 kg) dried continuously one after another batch at same relative humidity. Similarly two batches of paddy of 15kg (total 30kg) are also dried continuously at same relative humidity to compare the result. Generally, continuous drying experiments are conducted at night time as there is very small variation of relative humidityat night.

.**Table 3.** Details of experimental results for drying of three batches of paddy in the process-2

Sl.no	Amount of paddy in one batch(kg)	Total amount of paddy dried (kg)	Amount of moisture removal (%)	Avg. Atm. Humidity (%)	Time taken for moisture removal (hr)	Amount of biomass required (kg)
1	10	30kg	16.0,15.7,15.8	65	8.1	4.5
2	15	30kg	15.9,15.7	65	8.6	4.8
3	20	40kg	16.1,15.8	65	10.4	7.1

It is better to dry three batches of 10 kg of paddy due to more exposure of hot air to the paddy. In 15 kg of paddy due to increase of thickness contact of hot air to the paddy decreases and it will take more time to dry and biomass required is also more as compared to three batches of 10 kg paddy. But in comparison with process-1, process-2 requires less amount of biomass.

Variation of moisture with different thickness

Four batches of paddy of different amount (in weight) and of different thickness on the drying tray are dried at various times and approximately at same relative humidity (RH~65%) by using the different amount of biomass. It can be noted that the biomass is added to each batch. The heated air from the earlier batch needs less amount of heat input compared to the first batch (starting one) for drying purpose. Average moisture transfer of different batches of paddy with time is given.

First batch contains 10 kg of paddy of thickness ~2.5 cm requires two hours and thirty minutes for the removal of moisture from 30.6% (wb) to 14.65%(wb). It is observed that the initial moisture removal from the paddy in the beginning of the drying process is fast due to the removal of surface moisture. Surface moisture will readily evaporate when the grain is exposed to hot air but internal moisture evaporates slowly as it has to move away from the kernel to the outside surface due to surface forces. Second batch contains 15 kg of paddy of thickness ~3.5 cm and requires 4hrs 30minutes for the removal of moisture from 30.52% to 14.72%. The initial moisture removal for 15kg paddy is less than that of 10kg of paddy due to increase in thickness. Third batch contains 20 kg of paddy of thickness ~4.5 cm will require 5 hours 30minutes for the removal of moisture from 30.6% to 14.54%. The initial moisture removal of the paddy during the beginning time is fast due to surface moisture removal, but it is less as compared to 10 and 15kg of paddy due to increase in thickness. Fourth batch containing 25 kg of paddy of thickness ~5.5 cm will require 6hrs for the removal of moisture from 30.72% to 14.69%. Initial moisture transfer is more in case of 10kg than 15kg, 20kg, and 25kg because of more amount of heating surface area exposure. The increase in the thickness of the paddy increases the surface area exposure of paddy which in turn increases the moisture removal rate.

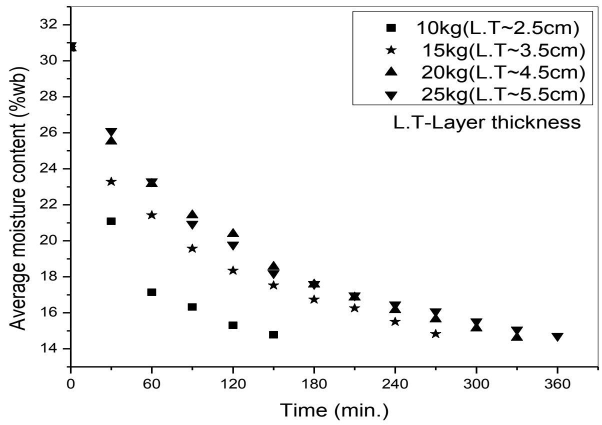

Figure 5. Variation of Avg. moisture content of different layer thickness of paddy with time at Relative Humidity-65%.

5. Conclusions

A simple dryer is designed and fabricated with locally available materials. The developed natural convection paddy dryer is capable of producing drying air temperature above 50^{0}C for paddy drying. It was found that drying time increases and initial surface moisture transfer decreases if the thickness of paddy increases. The amount of biomass required decreases for higher thickness of paddy layer as compared to the former by process 2. As explained earlier, the requirement of biomass is less for the subsequent batches after the starting batch with 10 kg paddy in process 2. The efficiency of the dryer is more in the continuous drying process of 10 kg paddy. There is sufficient loss of heat during loading and unloading of paddy and also after complete unloading of paddy.Hence efficiency of the dryer is less. The moisture removal rate is found to decrease with an increase in the drying mass. It is also found that there is a large variation of drying air temperature below the paddy tray. A sensible heat storage material can be used inside the dryer to decrease the variation of drying air temperature below the paddy tray and to increase the efficiency of the dryer by minimizing the heat loss.

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