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Performance Evaluation of Natural Convection Grain Dryer using Phase Change Material for Quality Drying of Paddy

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Abstract

Conservation of agricultural crops and minimization of grain losses is challenging issue in the present scenario. Effective use of thermal energy for drying of paddy and other cereals for maintaining proper quality is the quality drying process. Natural convection grain dryer is quite suitable for under developed and developing countries like India where rural electrification and advanced drying technology are not reachable .Natural convection dryer using biomass as a fuel can save the problems .In this present paper natural convection dryer along with phase change materials and its performance in effective drying of paddy has been studied. A detailed investigation has been carried out for drying of paddy at an average drying temperature of 50-58°C.Effective drying, quality of paddy and content of nutritional values have been explained. The drying efficiency was estimated 50.4% for drying of 100kg of paddy.

Keywords: Natural convection biomass dryer, Phase change material ,paddy, Drying efficiency.

1. Introduction

Food is the basic comfort and necessity of living beings. The major problem faced by the mankind is, the balance of food production and consumption. One of the most viable solution to the world's food problem involves reducing the food loss which occurs due to various reasons in developing countries causing a food loss from 10 to

40%. The food preservation is a method to reduce food loss and drying is the method that is being adopted since many centuries. In India sun drying is most commonly used in villages for drying of agricultural products like grains, vegetables. Open sun drying (OSD) is the traditional method for reducing the moisture content (MC) of paddy by spreading the grains in the sun. Sun drying is still preferred because it is cheap and abundant availability. This form of drying having so many drawbacks such as we can dry only during sun hours and temperature control is difficult. Overheating or re-wetting of grains can result in low milling quality as a result of cracks developing in the kernels. To overcome this, OSD solar driers using forced or natural convection circulation have been investigated by Ong (1999). For commercial applications, drying should be continuous. Many researchers have carried out studies on the solar dryers and their effectiveness in providing the quality products. However the restriction in availability of solar energy in odd periods of the year and other limitations opened an era to combine other drying methods basically for rural conditions. Bena and Fuller (2002) developed a direct-type natural convection solar dryer with simple biomass burner. El-Sebali et al. (2002) designed an indirect type natural convection solar dyer with sand as thermal energy storage material and for drying different products and the performance of the dryer with and without the storage material was compared and quality of the dried products was found to be better with storage materials. In rural areas, there is a need for simple, affordable combustion device, for efficient combustion of fuel woods which will provide required backup to thermal energy for drying. The objective of the present work is to develop a natural convection drier using biomass as fuel with latent heat storage materials (PhD Thesis IIT Guwahati) has been tested its performance for drying of paddy under metrological conditions of Guwahati, India. The quality drying of paddy was studied and the efficiency of drying was analyzed. The dryer was designed and fabricated at Indian Institute of Technology Guwahati, India.

2. Fabrication of the Dryer

The biomass burner is designed primarily for 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. This protects the product from contamination by smoke of the flue gas. A conical shape biomass burner(or furnace) of mild steel has been made as shown in figure, having bottom diameter of 60 cm and top diameter of 30 cm through which exhaust pipe of galvanized iron of diameter 6.35 cm and length of 2 m is connected horizontally. The flue gas exhaustion takes place through a 1.8 m length of 6.35 cm diameter pipe connected vertically. The conical furnace is kept on a rectangular stand (base) of 61 cm× 61 cm× 22 cm is covered from three sides. Only front side is opened and there is a fix projection of 30 cm to the outside from the front. 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 are easily disassembled to different parts when required for maintenance. For the feeding of biomass from the outside of the wall into the conical furnace, an inclined thin circular pipe whose one end 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 1.45 m×1.17 m×0.9 m encloses the biomass burner was constructed. There were eight rectangular holes out of which, six are along the length and two are along the width of brick wall perimeter at ground level for fresh air entry. The wire meshed drying tray provides an effective drying area of ~1 m^2. The temperature of the drying air can be controlled by maintaining the combustion in the burner. A schematic diagram of the natural convection dryer is shown in Figure 1. Dryer performance measurement, bio mass and paddy measurement, moisture measurement and temperature measurement were carried out with different instruments [PhD Thesis IIT Guwahati]. The dimensions and components of the of the dryer and phase change material properties are given in table 1. The determination of moisture content and efficiency are explained in subsections 2.1 and 2.2 respectively.

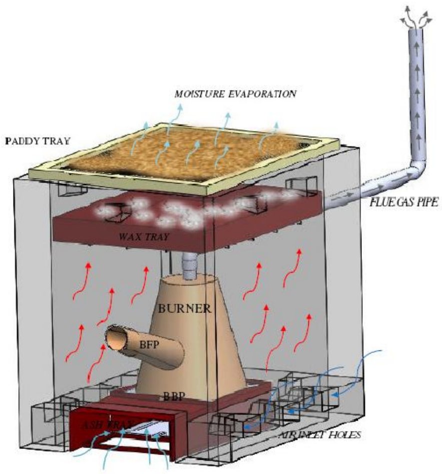

Figure 1: Schematic diagram of natural convection dryer using phase change materials.

2.1 Determination of moisture content

The quantity of moisture removed (*Mw*) from paddy can be found out from the following relationship [Forson, 2007]

$$M_w = \frac{W_p \left(M_{ip,wb} - M_{fp,wb}\right)}{\left(1 - M_{fp,wb}\right)} \qquad (1)$$

Where M_w is the mass of water removed from wet paddy (kg), W_p is the initial mass of the paddy to be dried (kg), M_{ip}, w_b is the initial moisture content of paddy on wet basis decimal, M_{fp}, w_b is the final moisture content of paddy on wet basis decimal.

2.2 Efficiency of the drier

The drying efficiency of dryer is defined as the ratio of energy used to evaporate the moisture from the paddy to the energy input to the dryer by biomass.

$$\eta = \frac{WL}{MC} \tag{2}$$

where, *W* is the weight of water evaporated (kg), *L* is the latent heat of evaporation of water (MJ/kg), *M* is the Mass of biomass fuel used in the furnace (Kg), *C* is the calorific value of biomass fuel (MJ/kg).

Table 1: Component and specifications of the drying chamber with storage materials.

Component	Specifications	Component	Specifications
1.Drying Chamber a. Shape b. Dimensions c. Thickness d. materials	Rectangular 145cmx117cmx90cm 13cm Brick, Cement, Sand	2.Paddy Tray a. Dimension b. Wire mesh type c. Thickness of wood plate	112 cmx85 cm Ms wire of 2 mm gap 5 cm
3. Wax tray a. Shape b. Dimension c. Thickness d. Materials	Rectangular 120cm × 93cm × 12cm 5mm Mild steel	4. Paraffin wax a. Grade b. No. of carbon atoms. c. Melting temperature range d. Flash point temperature e. Storage density f. Thermal conductivity g. Specific heat	II 25 45□C-60□C 280□C 800kg/m3 0.24W/m □C 2.0kJ/kg

3. Results and Discussion

Experiments were conducted in the developed dryer in the presence of phase change materials (PCM) to store the thermal energy and to release heat at constant range of temperature for quality drying of paddy. 20 kg of Paraffin wax of grade-II has been selected as the PCM based on its melting and solidification temperatures. Experiments are conducted to study the characteristics of paraffin wax grade-II and to use the constant range of temperature of PCM for quality drying of paddy. To melt 20kg of paraffin wax and to maintain the constant range of heat release rate a 1.75kg of biomass is required. A large amount of heat is absorbed by the paraffin wax during the melting and same is released during the solidification for longer period of time. Once the melting of paraffin wax starts it is not necessary to combust the biomass any more. The melting process completes with the heat available in the dryer. All the experiments reported in subsequent sub-sections are conducted with 20 kg of paraffin wax. Average drying air temperatures below the paddy tray during drying of paddy were measured in the range of 50^{0}C - 58^{0}C after a period of 70 minutes of combustion of biomass in the furnace. All the experiments were repeated for 3 to 4 times and average value of the parameters was reported. Experiments were conducted by considering 10 kg of paddy respectively.

Table 2: Characteristics study of paraffin wax.

Amount of paraffin wax (kg)	Melting range of temp. (□C)	Time taken for melting of paraffin	Time taken for solidify to come to 50□C	Amount of biomass required to melt (kg)
20	~48.6- 62.4	~50 min.	~3hrs 20 min.	1.75

Table 3: Input parameters with PCM.

Sl No	**Particulars**	**Ranges**
1	Ambient air temperature	15□C -17□C
2	Relative humidity	65%
3	Amount of paddy per batch	10 kg
4	Drying air temperature	48 □C -58□C
5	Amount of paraffin wax	20kg
7	Initial moisture content of paddy grain	30% (approx)
8	Final Moisture content of paddy grain	14-15%

Loading of paddy in the tray is done when the drying air temperature in the plenum chamber is above 45^{0}C. It is found that the solidification of 20 kg of molten paraffin wax releases heat at constant range of temperature 50^{0}C-60^{0}C for three hours and twenty minutes. When temperature of drying air falls near to 50 ^{0}C during drying process, an additional amount of biomass (0.500 kg) is supplied to the furnace so as to maintain the drying air temperature above 50 ^{0}C for another 50 minutes.

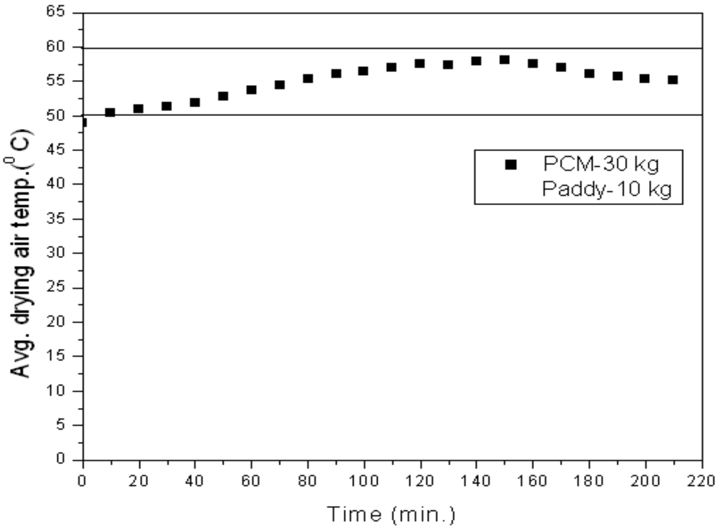

Figure 2: Drying air temperature with time during experiments with PCM.

The minimum and maximum drying air temperature during drying period for 10kg of paddy is observed to be 49^0C and 58^0C, respectively. Figure 2 shows the variation of drying air temperature during drying of 10 kg of paddy. Figure 2 shows the variation moisture transfer rate from 10kg of paddy in presence of PCM. The initial and final moisture content from 10 kg of paddy is from 30.1% to 14.6%. Relative humidity during the moisture transfer is maintained 65%. It is observed from the Figure 3 that the time taken for the transfer of moisture from 10 kg is 3hrs 30 mins.

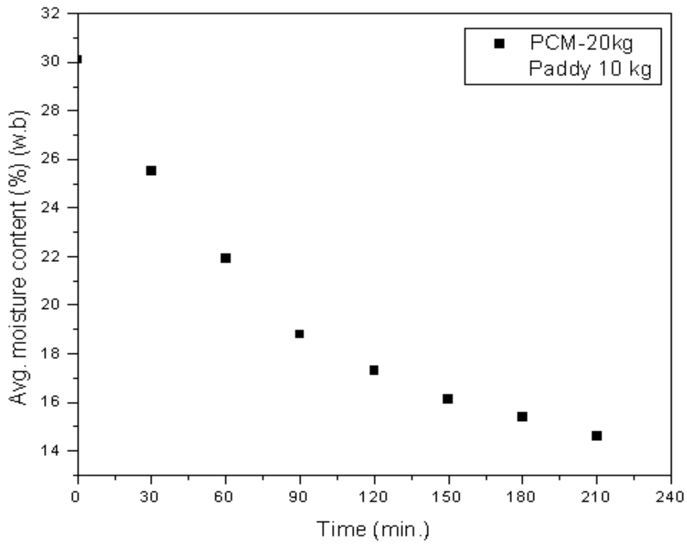

Figure 3: Variation of Average moisture content of 10kg of paddy with time with PCM at RH-65%.

In order to test the feasibility of the dryer in terms of fuel saving as well as drying time, series of experiments are conducted in the present dryer in both batch and continuous process. Tables 4.3 present the drying efficiency for batch drying (BD) and continuous drying (CD) process, respectively. It was observed that the drying efficiency in continuous process is better than that of the batch process with significant reduction in biomass requirement. Experiments performed with PCM for continuous drying of 100 kg of paddy reveals that the drying efficiency of 50.4% can be achieved with the range of moisture content 30-14.5%.

Table 4: Drying efficiency in batch wise and contineous process.

Sl. No	Amount of paddy in one batch(kg)	Total amount of paddy dried (kg)	I.M.C	F.M.C	Total amount of moisture removed (kg)	Amount of biomass required (kg)	Drying Efficiency (η) (%)
1	10 (BD)	30kg	30.2,30.1,30.4	14.4,14.5,14.7	5.5	7.5	9.8
2	10(CD)	30kg	30.4,30.2,30.5	14.5,14.8,14.6	5.5	3	24

4. Conclusion

The performance of natural convection drier using biomass as fuel with phase change materials (paraffin wax) as thermal energy storage material has been fabricated and tested for drying of paddy. The paddy was dried from initial moisture content 30.1% to 14.6% for 30 kg of paddy in continuous drying process. This type of driers is very suitable in rural places throughout the world where electricity is not available.

5. Acknowledgement

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