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Short Communication

Study on in-bed drying system for the drying of paddy in Assam

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Abstract

In this study, in-bed dryer was developed for the deep bed drying analysis of paddy available in Assam. Experiment was done by taking a bed height of 30 cm, proper air velocity and an optimum temperature of 35 . For analysing the deep bed drying behaviour of paddy finite difference method, especially forward euler's method was used. The algorithm for PDE modeling of the deep bed drying analysis of paddy was developed in MATLAB R2009a. It was used for predicting the temperature and moisture profile at different levels of the dryer and finally to validate the experiment. The validation of the developed PDE model was done on the basis of predicted values of the temperature profile and final moisture contents of the dried paddy.

Introduction

Paddy is one of the major staple crops in the world. Paddy (rough rice) is harvested at high moisture content, usually in the range of 22–30% (wb). Harvesting of paddy with high moisture content normally leads to high yields and less damage and prevents field losses due to dropping and shattering. Drying is an important step in order to preserve the paddy grain for a longer period or to process it into white rice. However, drying is an energy intensive process and it significantly affects the quality of rice. Severe drying conditions may lead to high fissuring, which can increase the number of broken rice. As broken rice considerably lowers the market value, an effective drying process is required to produce optimal HRY with minimum energy input.

A two-stage drying is an effective technique that could be used for seed drying due to its performance in high moisture food grain drying. If ambient air can be used for the second stage (in-store) drying, it could reduce energy cost and be efficient if the initial moisture content of grain entering the dryer is less than 19%wb (Soponronnarit, 1997). Therefore, drying of grain should be done rapidly from a high moisture level down to around 18-19%wb before being moved to an in-store dryer. (Morey *et al.*, 1978) and (Muhlbauer *et al.*, 1981) studied that maize drying at high temperature for the first stage followed by low temperature drying for the next stage can reduce energy consumption as compared with a high temperature drying. In terms of product quality, (Bhattacharya *et al.*, 1971) found that two stage drying process can reduce the breakage of rice during milling.

Normally, specific types of dryers are used for each stage in case of two stage drying technique. Fluidized bed or spouted bed dryer is used for the first stage drying due to its high drying rate. In the second stage the grain could be dried slowly as the grain obtained from first stage with 18%wb could be stored under humid tropical conditions for up to 21 days without quality loss (Tumambing, 1993). For this reason dryer with low air temperature and low air velocity (such as in-store/in-bed dryers) are normally selected for the second stage of drying. These systems have made it commercially feasible to dry grain in deep bins, with low-air volumes and very little supplementary heat.

In this study, paddy sample after drying in the first stage drying system namely fluidized bed dryer up to 18-19%wb, has been dried in the second stage drying systems namely in-bed drying. This is due to the reason that in-bed dryer can be effectively used in area like Assam under local weather condition. The objectives of the study was to study deep bed drying behavior of paddy under the local weather condition of Assam by using in-bed drying system.

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Materials and Methods

Paddy sample

Seed of paddy was used for this study.Local paddy variety 'Aijong' (*Oryza sativa* Linn) available around the Tezpur University, was collected for the sample.

In-bed dryer

The in-bed dryer was used for the deep bed drying of paddy from 16-22% wb (moisture content of paddy after harvesting followed by initial hour sun drying) moisture content to safe moisture level (<14%wb) under ambient air temperature and low air velocity.

Development of the dryer

The dryer consists of two section.One section is Below the seed bed, known as Inlet section having length 21 cm and Diameter 20 cm (same as the fluidized dryer chamber used for intial stage drying) and another section above the seed bed, known as outlet section having length 45 cm and Diameter 20 cm.The inlet section consists of two holes for the air velocity and relative humidity measurement of the drying air befor entering into the seed bed.The outlet section consists of 5 holes in oneside for the temperature measurement with the help of sensors. The sectional view of the dryer are shown in Figure 1.

Materials and equipment

For the in-bed drying experiment, the following materials and equipments were used: 1) Paddy sample 2) Anemometer for the air velocity measurement 3) Temperature sensors 4) Relative humidity sensors 5) In-bed dryer setup.

Design of experiments

The in-bed drying was done for the drying of paddy that has initial moisture content of 16-22%wb. The experiment continued up to safe moisture content (≤14%wb) at ambient temperature with the help of grain aeration. The drying experiment was conducted at 35 and 2.2 m/s air velocity for the paddy having initial moisture content of 20% (wb). The depth of bed, for the in-bed drying was 30 cm.

Drying procedure

In this study, paddy was dried by using in-bed dryer. The dryer was operated at the ambient air temperature and relative humidity. The velocity of air for the dryer was kept very low. The drying experiment

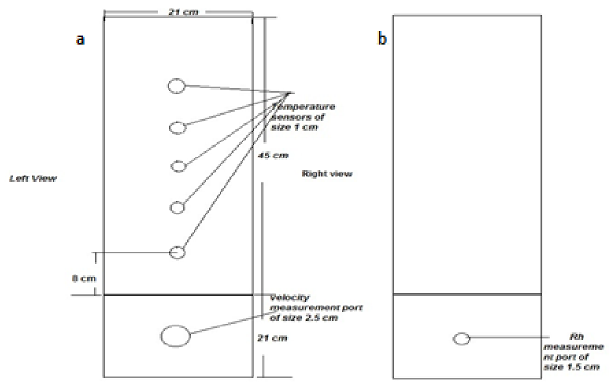

Figure 1. Schematic views of the dryer: (a) left view and (b) right view

was conducted up to 13% (wb) moisture content of paddy. The stopwatch was started immediately after starting the air blower. In the experiments, temperature was measured at three different levels with sensors. The final moisture content of the paddy samples were measured at the end of experiment. At the mean time relative humidity, temperature and air velocity of the inlet were measured.

Non-equilibrium model for the deep bed drying analysis

Due to accuracy and validity for cereal drying, non-equilibrium models are mostly used. The non-equilibrium model with the combination of partial differential equations (PDE) is given below:

For an elemental bed of unit cross section the mass and energy balance in an elemental bed of unit cross section (Sharp, 1982) results in three differential equations:

Mass balance for moisture:

$$G\frac{\partial H}{\partial x} = -\rho_g \frac{\partial M}{\partial t} - \varepsilon \rho_a \frac{\partial H}{\partial t} \tag{1}$$

Energy balance of air:

$$G(c_a + c_v H)\frac{\partial T}{\partial x} = -\rho_g c_v (T - \theta)\frac{\partial M}{\partial t} - h(T - \theta) - \varepsilon \rho_a (c_a + c_v H)\frac{\partial T}{\partial t} \tag{2}$$

Energy balance for grain:

$$\rho_g (c_g + c_w M)\frac{\partial \theta}{\partial t} = h(T - \theta) + \lambda \frac{\partial M}{\partial t} \rho_g \tag{3}$$

By considering dryer as a combination number of thin layers (Sharp, 1982) assuming the work of previous studies (Mandas and Habte, 2002), the time derivative terms and can be neglected as the contribution of the terms in the above equations is very small, compared to the other terms in the system. So, the system of PDEs can be reduced to following set of equations:

$$\frac{\partial H}{\partial x} = -\frac{\rho_g}{G}\frac{\partial M}{\partial t} \tag{4}$$

$$\frac{\partial T}{\partial x} = \frac{1}{G(c_a + c_v H)}\left(\rho_g c_v (T-\theta)\frac{\partial M}{\partial t} - h(T-\theta)\right) \tag{5}$$

$$\frac{\partial \theta}{\partial t} = -\frac{1}{\rho_g (c_g + c_w M)}\left(h(T-\theta) + \lambda \frac{\partial \theta}{\partial t}\rho_g\right) \tag{6}$$

The set of equations (4-6) involves four unknowns viz., , , and . The fourth equation used along with equations (6-8) to solve for these unknowns is the drying rate equation. For barley, Lewis equation is used (Sharp, 1982; Sun and Woods, 1997), which is written as,

$$\frac{\partial M}{\partial t} = -k_d (M - M_e) \tag{7}$$

where,

$$k_d = K_0 \exp(-E_a / T) \tag{8}$$

E_a and K_o are the two coefficients, having specific values for material being dried.

Results and Discussion

Temperature profile of the drying

Figure 2 shows the temperature profile of the different layers during in-bed drying of paddy. From the figures, the temperature during early drying period is relatively higher at the bottom level than upper level. Depending on the specific air flow rate and initial moisture content of paddy, when a particular period of drying time elapses, the temperatures at the lower and upper parts of bed approach together. At the end of drying, moisture content at each level reaches below 14% (wb).This indicates the uniform heat and mass transfer throughout the drying experiment.

Simulation of the in-bed drying system

The simulation and modeling of the in-bed drying was done by using finite difference method. For the present study, forward Eulers method was used.The code for the PDE modelling was developed in MATLAB R2009a. It was used for predicting the temperature and moisture profile at different levels of the dryer and finally to validate the experiment. Figure 3 and 4 shows the predicted moisture and temperature profile for different layers of the in-bed drying system.

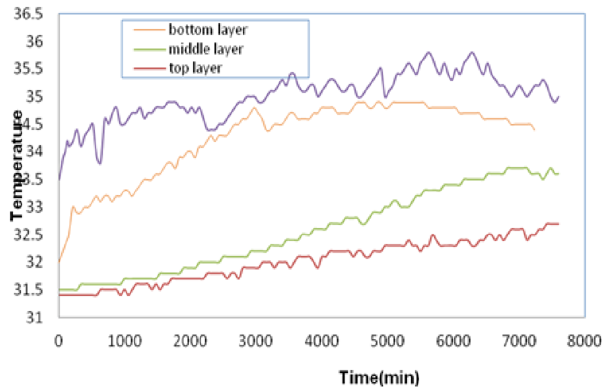

Figure 2. Temperature profile of the inlet air and at different levels of the in-bed dryer

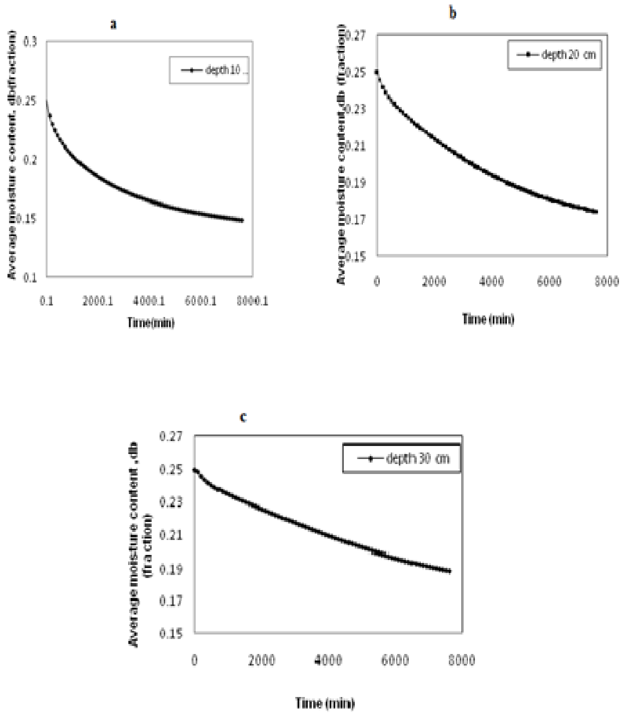

Figure 3. Predicted moisture profiles of different levels of the in-bed drying system at 35°C temperature: (a) at depth 10 cm (b) at depth 20 cm and (a) at depth 30 cm

Validation of the developed model for the in-bed drying system

For the validation of the developed PDE model, predicted values of the temperature profile and final moisture contents of the in-bed drying of paddy was compared. It was observed that for the temperature profile of the bottom and middle layer, it gives value of 0.72 and 0.60 respectively. Predicted final moisture content was validated with a value of 0.705132592 and MSE of 0.000248053. Figure 5 shows the plot between the predicted and experimental values of the final moisture contents and temperature profile of the bottom and middle layer of the dryer.

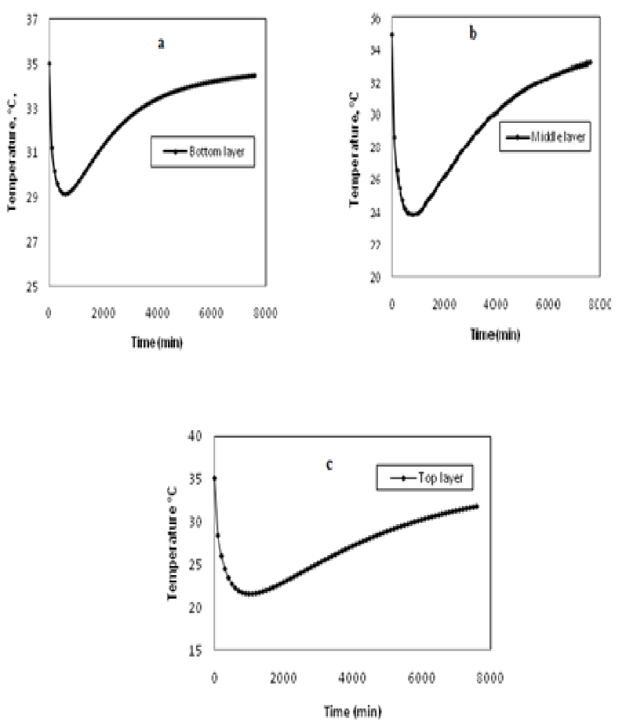

Figure 4. Predicted Temperature profiles of different levels of the in-bed drying system at 35°C temperature: (a) at the bottom layer (b) at the middle layer and (c) at the top layer

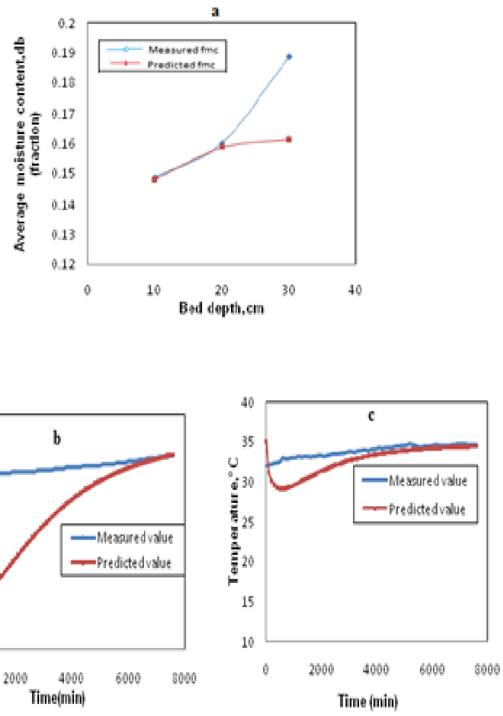

Figure 5. (a) Experimental validation of the final moisture content of the paddy at different levels. (b) and (c) experimental validation of the temperature profiles for the middle and bottom layer respectively

Conclusion

In this study, in-bed dryer was developed for the deep bed drying of paddy available in Assam. Experiment was done at a optimum temperature of 35 by using in-bed dryer setup. In this dryer, three levels namely top, middle and bottom layer were designed at a distance of 10cm for each level. By taking a bed height of 30 cm, proper air velocity and a heating arrangement, experiment was carried out. For analysing the deep bed drying behaviour of paddy finite difference method, especially forward eulers method was used. The algorithm for PDE modeling of the deep bed drying analysis of paddy was developed in MATLAB R2009a. It was used for predicting the temperature and moisture profile at different levels of the dryer and finally to validate the experiment. The validation of the developed PDE model was done on the basis of predicted values of the temperature profile and final moisture contents of the dried paddy. It was observed that the temperature profile at the bottom and middle layer gives R^2 value of 0.72 and 0.60 respectively. Predicted final moisture content was validated with a R^2 value of 0.70 and MSE of 0.00024.

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