Kinetics and Mathematical Modeling of Drying of Parboiled Paddy in a Packed Bed Dryer

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ABSTRACT

Drying characteristics of 2 types of parboiled paddy ("Nadu" & "Samba") was investigated in a packed bed dryer. Drying experiments for both paddy types were carried out at three different hot air temperatures 35ºC, 45ºC and 55ºC by keeping constants hot air flow velocity and bed height as 5.8 m/s and 15 cm respectively. Moisture content was measured at different time intervals. Experimental results were fitted to three thin layer drying models; Midilli et. al., Weibull et. al. and Page. Statistical indicator; Root mean square error (RMSE) showed Midilli et. al., Weibull et. al. models give better fit to the experimental values. The absence of the constant drying rate period in drying curves show the drying of parboiled paddy lies totally in the falling rate period where the drying rate is controlled by the moisture diffusion. Maximum drying rates were observed for both paddies. Effective moisture diffusivity values were calculated for different temperatures. The Activation energy of "Nadu" and "Samba" are calculated based on the Arrhenius equation are 33389.024 J/mol and 16776 J/mol respectively.

Keywords: Paddy Drying, Packed bed Dryer, Thin Layer model

INTRODUCTION

Paddy is the major staple food source used in Sri Lanka. Initially harvested paddy grain contains 18-27% moisture content by mass dry basis (Soponronnarit et al., 1999). More than 50% of initially harvested paddy in Sri Lanka dried using methods such as sun drying, heated air drying and in-storage drying (IRRI, 2013).) after parboiling due to prolong storage life, easier dehulling, less broken grains during milling, to reduce insect attack and to increase the vitamin B. Moisture content of parboiled paddy after steaming process is in the range of 43-55% (Rao et al., 2007).

Remaining water encourage mold growth, natural respiration in grain, development of insects, rice yellowing (Izadifar et al., 2006) and lowers the germination rate. Paddy moisture content is reduced to about 12-14% on wet basis (Igathinathane et al., 2008).

Food and grain drying have been paid much attention by researchers. Sun drying is the preferred method in Sri Lanka due to its low cost. However, in rainy days sun drying is impossible. Viability of using fixed bed dryer for parboiled paddy is examined in this research.

Objectives of this research is to model drying kinetics and study on heat and mass transfer characteristics of packed bed dryer.

METHODOLOGY

Paddy was soaked in water for 12 hours at 30ºC. Paddy husks floating on the water were removed. Then, steaming was done for 15 min using stainless steel steamer with a wire mesh. After the steaming, a sample was taken and measured the weight. Then it was put in the oven to evaporate water at 110ºC. Packed bed column was used to dry the paddy. Air temperature and air flow rate were set in the apparatus. Temperature of the air is provided by a heater assembled to the apparatus. After achieving the required temperature and air flow rate of air, parboiled paddy was fed to the

packed bed column through an opening from the top to a required height and closed the opening using the lid of that opening. Then, a sample was taken after 10 minutes from an opening at the bottom of the packed bed column and closed the opening with its lid. Weight of the sample was measured and recorded. Then put it in the oven. Likewise, 10 other samples were taken, measured and recorded the weight and put in the oven to evaporate the water.

The moisture content (MC) of the paddy was calculated (eq. [1]) and plotted as a function of the time and calculated MC values were converted to moisture ratio (MR) values (eq. [2]) for three different temperatures.

$$MC = \frac{W - W_d}{W_d} \quad [1]$$

Where, W –Weight of the wet paddy, W_d- Weight of the Dry paddy

Rate of drying (N), kg of moisture evaporated/kg of dry material/ min, was calculated using the equation [2],

$$N = \frac{d(MC)}{dt} \quad [2]$$

Moisture Ratio (MR) is calculated by,

$$MR = \frac{MC_t}{MC_o} \quad [3]$$

MC_t – Moisture content at time t, MC_o – Initial moisture content

By assuming that the paddy has a rough spherical shape, applying Fick's second law of diffusion, (MR) of the paddy at any given time (eq.[4]). (Bhagwati Prakash1 and Zhongli Pan1, 2011).

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left[\frac{-n^2\pi^2}{R}\left(\frac{D_{eff}t}{R}\right)\right] \quad [4]$$

Where, n – number of terms, R- Equivalent Particle radius (m), D_{eff} - effective moisture diffusivity (m^2/s), t – time (s)

Effective moisture diffusivity D_{eff} can be determined from the slope of curve of ln (MR) vs. time. The relationship between effective moisture diffusivity D_{eff} and temperature is represented by an Arrhenius type equation,

$$Deff = D_0 exp\left(\frac{-Ea}{RT}\right) \quad [5]$$

Where D_0 is the pre-exponential factor of the Arrhenius equation ($m^2.s^{-1}$), Ea is the activation energy ($kJ.mol^{-1}$), R is universal gas constant (8.314 $kJ.mol^{-1}.K^{-1}$) and T is absolute temperature (K).

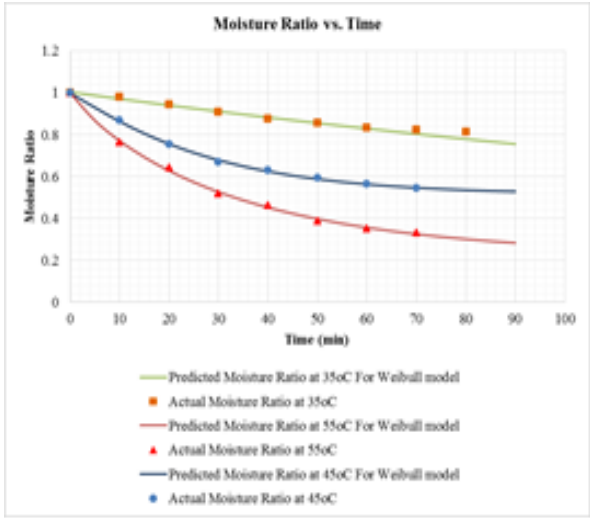
The activation energy (E_a) is calculated from the slope of the plot ln (D_{eff}) versus 1/T.

RESULTS AND DISCUSSION

The experimentally determined moisture content values were converted to the moisture ratio values and the data were fitted to 3 different thin layer drying models (Fig 1). The model parameters were determined using Excel Solver.

Table 1Thin Layer Drying Models (B.M.W.P.K. Amarasinghe, 2018)

Model Name	Model Equation
Page	$MR = \exp(-kt^n)$
Midilli *et al*	$MR = a\exp(-kt^n) + bt$
Weibull	$MR = a\exp(-kt^n) + b$



Experimental results and model predicted results using the Midilli et.al. equation.

Figure 9 Moisture ratio vs. Time curve for "Nadu" at different temp.

The rate of drying can be determined using the gradient of moisture content (MC) vs time plot and the Fig. 2 shows drying rate (N) as a function of moisture content at three different hot air temperatures. Constant drying rate period is in existence showing that drying of paddy in packed is completely under the falling rate period. This shows diffusion of moisture within the solid is the rate controlling step in paddy drying. This result is in agreement with the previous workers results on drying of food materials where the constant drying period is negligible.

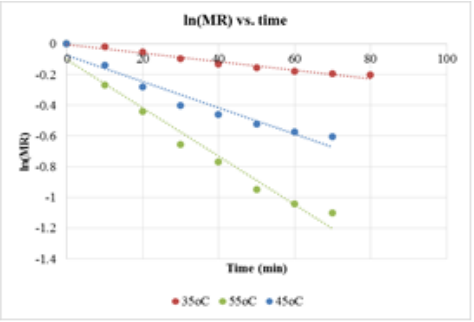


Figure 10 Drying rate vs. Moisture content curves for "Nadu" at different temp.

Maximum drying rates observed for "Nadu" are, 1.037, 0.57 and 0.163 kg moisture/kg of dry material/ min for 35ºC, 45ºC and 55ºC temperatures respectively.

Observed diffusivity values are 6.9 x 10^{-10}, 2.13 x 10^{-9}, 3.9 x 10^{-9} m^2/s for temperatures of 35ºC, 45ºC and 55ºC respectively. Activation energy calculated was 33389.024 J/mol. Similarly above calculations and experiments were conducted for "Samba" as well.

CONCLUSION

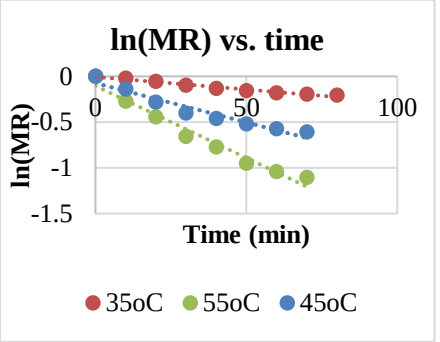


Figure 11 ln(MR) vs. time curves for "Nadu" at difference temperatures

Packed drying kinetics of parboiled paddy was studied for 2 types of paddies "Nadu" and "Samba" Experimental data was fitted to 3 thin layer drying models. The Midilli et. al., Weibull et. al. models showed statistically better fit compared to other models. Similarities of the model parameters were observed and the significance of the parameters was analyzed. The drying rate constants obtained for "Nadu" by Weibull model were 0.003, 0.02 and 0.04 min-1 for temperatures of 35ºC, 45ºC and 55ºC respectively. The Effective moisture diffusivity increased with temperature and values were in the range 6.9 x 10^{-10}-3.9 x 10^{-9} m^2/s. The Activation energy of "Nadu" calculated based on the Arrhenius equation is 33389.024 J/mol. Drying of "Nadu" parboiled paddy under high temperature is recommended since parboiled paddy should be dried up to 12% MC. The time required to dry parboiled paddy from 43% MC to 14% MC wet basis under 65ºC temperature in packed bed is 70 minutes compared to several days under sun drying.

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