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Energy and rice quality aspects during drying of freshly harvested paddy with industrial inclined bed dryer

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ABSTRACT

The performance evaluation of any industrial dryer regarding energy consumption and product quality should be assessed to check its present status and to suggest for further efficient operation. An investigation was carried out to evaluate the impact of drying temperature and air flow on energy consumption and quality of rice during paddy drying with industrial inclined bed dryer (IBD) with average holding capacity of 15 ton in the selected complexes of Padiberas Nasional Berhad (BERNAS)-the national paddy custodian of Malaysia. In reducing paddy moisture content (mc) from 22% to 23% wet basis (wb) down to around 12.5% wb, the final mc, the specific electrical (in terms of primary energy) and the specific thermal energy consumption were found to be varied between 1.44 to 1.95 MJ/kg water evaporated and 2.77 to 3.47 MJ/kg water evaporated, respectively. Analysis revealed that the specific electrical energy consumption was around 20% lesser and the specific thermal energy consumption of IBDs was around 10% higher during drying with air temperature of 41–42 °C than drying with 38–39 °C in reducing paddy mc from 22% to 23% (wb) down to around 12.5% (wb). However, paddy being with almost same initial mc dried using drying temperature of 38–39 °C, IBDs yielded 1–4% higher head rice yield while milling recovery and whiteness were comparable at acceptable milling degree and transparency. The bed air flows between 0.27 and 0.29 $m^3\,m^{-2}\,s^{-1}$ resulted in higher head rice yield slightly while its effect on drying time was not prominent so much. For paddy with initial moisture content below 23% wb, it is recommended that drying air temperature should not be higher than 39 °C in order to maintain rice quality at reasonable energy consumption.

1. Introduction

Paddy drying is a serious issue in all paddy-producing countries. It sometimes becomes a crucial problem in humid tropical climates since it is the most critical operation after harvesting rice crop. Delay in drying, incomplete drying or ineffective drying will reduce grain quality and enhance postharvest losses. In tropical countries, the paddy is usually harvested at high moisture content between 20% and 25% wet basis [1,2]. Although new methods such as: combined microwave or infrared–hot air drying [3,4], super-heated steam drying [5] and spouted bed drying [6,7] have been reported as efficient drying methods for quality rice but their use for industrial purposes are still limited. The most common dryer for paddy drying in Asia is fixed deep bed dryer either in the form of rectangular bins such as flat bed and inclined bed or circular bins [8]. However, inclined bed dryer (IBD), as illustrated in Fig. 1, is very popular as single stage dryer for complete drying of paddy in commercial rice mills of Malaysia. Recently, IBD is found to be used as second stage dryer after fluidized bed dryer (FBD) in very few drying complexes of Padiberas Nasional Berhad (BERNAS)-the national paddy custodian of Malaysia. IBD is a type of deep bed or fixed bed dryer in which the drying bed is inclined to get advantages for easy and faster discharge of paddy after drying. This dryer is usually used for drying of the high moisture (20–26% wb) paddy with drying bed usually fixed at 1.0 m. The moisture gradient in final product after drying with fixed bed drying is usually higher (3–4%) [8]. A numerous reviews on modelling and simulation on deep bed drying were found where-in results were discussed based on laboratory experiments [2,9–15], while the industrial scale study results were seldom reported in scientific journal. The drying characteristics and further analysis of the drying rate periods of Malaysian paddy were studied by Daud et al. [16] and Law et al. [17,18]. However, information on attempts to use IBD specifically for industrial drying of freshly harvested paddy containing high moisture and impurities are still scare.

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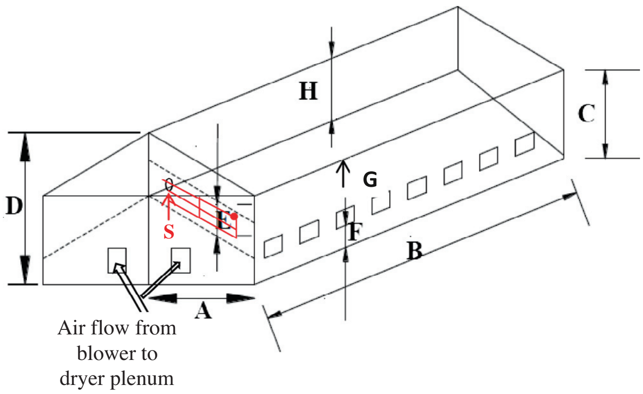

Fig. 1. Schematic diagram of industrial inclined bed drying chamber. (A width; B length; C height of edge; D middle height; E actual paddy bed depth; F out let height; G paddy storage depth; H height of discharge carrier from top of paddy bed; S sample collection points at paddy bed.)

Paddy drying is a highly energy-intensive process and sensitive to the quality of rice. The energy cost of the industry is possible to be reduced if an in-store dryer is used after the first-stage drying by LSU dryer [19]. To compare the energy consumption between industrial drying options, the observational data of drying paddy with the industrial scale dryers must be obtained [20]. It is well known that if the drying bed is more than 20 cm, then the bed is termed as deep bed. However, the suitable or optimum bed thickness for a specific temperature to dry paddy with particular initial moisture content to achieve better quality product at reasonable energy consumption is important for any dryer. Inconsistent operating parameters, such as drying air temperature, drying time and air flow rate among the drying process lines were reported during industrial drying [21]. The effect of drying temperature on rice quality and energy consumption at this higher bed thickness of 1.0 m used in the industry warrants a thorough study for further efficient operation of the dryer. Necessarily, the performances of industrial dryers should be assessed to check its operational status.

Therefore, this study was undertaken to assess the actual drying practices using IBD in the two commercial paddy drying complexes of BERNAS. The effect of temperature and air flow used in both complexes on drying behavior, energy consumption and final quality of product have been evaluated to suggest in selecting suitable operating parameters for efficient operation of the dryers.

2. Materials and methods

This research was conducted in two paddy processing plants of BERNAS: one at Bukit Besar, Kedah and another at Simpang Empat, Perlis, Malaysia. The dryers consist of inclined drying bed (10.72 m × 2.92 m and 10.29 m × 3.05 m) with 9.5 mm stainless steel sieve installed at 38–45° inclination, blower with 1.524 × 1.31 × 0.533 m impeller and 18.65 kW motor were used. Freshly harvested paddy 'MR219' variety, which is produced widely in Malaysia, was collected from the farmer's field at Kuala Perlis and Bukit Besar, Kedah and used for all the experiments. The drying operations with detailed operating conditions used during this study are illustrated in Table 1. Shed drying using ambient air was followed for drying of control samples. Necessary data such as the amount of paddy, moisture content, impurities in paddy, drying air temperature, drying time, air flow and motor power were recorded. The drying air was heated from the heat produced by the combustion of rice husk in cyclonic furnace. From each IBD, the paddy samples were collected from 27 points at 2–5 h interval. Higher interval of 5–3 h was considered at the beginning of drying in each IBD due to a very low moisture drop, while this interval was 2 or 1 h towards the end of drying process. This was adopted to ensure an appropriate final drying stage as well as to avoid over drying of paddy. In order to determine sample moisture content the whole bed was divided into three sections along length and depth as shown in Fig. 1. The length of the paddy bed was specified as front, middle and back, while the depth of the paddy was specified as the top, middle and bottom. The top average, middle average and bottom average were defined as the average moisture content of samples taken from every nine points from the top, middle and bottom sections, respectively, while the average moisture content was calculated as the arithmetic mean of paddy moisture content collected from the above-mentioned 27 points of each IBD. A 1.25 m long Hand Auger was used to collect the samples from above mentioned points. Indeed, sample collection from the above mentioned 27 points of each dryer was really a terrible and troublesome job which was solely dependent on few other physical facilities in the complex hence it was not possible to maintain equal interval. The moisture content of the paddy was measured by the Satake digital grain moisture tester model "SS-6" with an accuracy of ±0.5%. The moisture meter was previously calibrated with standard oven method (temperature 103 °C for 24 h) through determining paddy moisture content at the laboratory. Meanwhile, drying air temperature and relative humidity were measured by K-type thermocouple (HANNA, Italy) with ±0.5 °C accuracy and Thermo Hygrometer (H19564, HANNA, Taiwan), respectively. The Thermocouple and Hygrometer were also tested to check their accuracy with another thermometer and psychrometer, respectively at the laboratory before starting for using data recording in this study. The inlet air velocity of dryers was measured by Thermal Anemometer (TESTO 4235, Italy) with ±0.03 m/s accuracy. The cross-section area at the point of velocity measurement was measured previously and the total volume of air passing through each IBD was calculated by continuity equation (Eq. (a)). Bed air velocity of each dryer was calculated using the same equation.

$$Q = A \times V \tag{a}$$

2.1. Analysis of specific energy consumption

The specific energy consumption can be one of the main indicators for evaluating the performance of a dryer. Lower the specific energy consumed by a dryer confirms its better performance. The energy consumed was divided into heat for heating air and electricity for driving blower fan. The collected data were used for calculating the energy consumption of the paddy drying by Eqs. (b), (c), and (d) agreeing with Jittanit et al. [7]. Similar to Soponronnarit et al. [22,23] the efficiency of a power plant to convert thermal to electrical energy has been considered as 38.5%. Thus conversion factor of 100/38 = 2.6 was used in Eq. (b) to convert electrical energy to primary energy .

The total water evaporated from paddy in each batch was calculated using material and solid balance equations (Eqs. (e) & (f)). Dryer performance based on the specific electrical and thermal energy consumption were finally calculated in mega joule (MJ) per kg water evaporated. The total specific energy consumption was simply calculated by summing up both electrical and thermal energy values.

$$E_{\text{elec}} = 2.6P \times t \tag{b}$$

$$E_{\text{heat}} = m_a C_a (T_{\text{mix}} - T_i) \tag{c}$$

$$m_a = Q \times \rho_a \times t \tag{d}$$