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Drying of Paddy in a Laterally Aerated Moving Bed Dryer at Ambient Temperature

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The existing industrial dryers commonly used for paddy drying such as fluidised bed dryer (FBD), re-circulating batch dryer, and continuous bed dryers, despite its useful ability, have its limitation in terms of capital and operating cost, flexibility of processing in small and large scale, and requirement of skilled labours. In this study, a commercial scale Laterally Aerated Moving Bed (LAMB) dryer was designed, fabricated, and tested in a local rice mill. This new technology is consisted of a 4.7 m tall LAMB vessel containing perforated inner tube and a mesh layer, electrical air heater, and conveyor systems for paddy loading and withdrawal. The LAMB dryer had a capacity of 2 t of paddy per batch. The performance testing at ambient aeration temperature was done. The results showed that the paddy could be dried to the desired moisture content using ambient air (30 - 35 °C), at a fixed air flow rate of (530 m^3/h), 5 h air blowing, and 1 h tempering time. The moisture content was reduced from 17.87 to 13.04 % (w.b.) in 5 h, and reduced further to 12.04 % (w.b.) after undergoing tempering for 1 h. The drying uniformity analysis showed that the percentage standard deviation for vertical drying analysis is 16.94 %, whereas the horizontal drying analysis recorded only 2.93 %. The drying time was shorter than the time taken by typical inclined bed dryers. The LAMB drying uniformity was relatively higher compared with the recommended uniformity by IRRI, which is less than 1 %. This was likely due to the low heating temperature used making the temperature gradient across the height as insignificant. More experiments are currently being carried out to achieve high drying uniformity vertically and horizontally.

1. Introduction

Rice is a staple crop, consumed by half the earth population as a basic necessity (Wasim, 2002) including diets, and source of income. This crop is one of the major economic contributor (Akowuah et al., 2012) , especially in Asia. Department of Statistics Malaysia (2015) shows an increment of production of paddy by 41 kt (1.6 %) on 2014, as compared to the year before, making the domestic consumption to be at its stable quantity of 2.85 to 2.9 Mt in 2015/2016 (Wahab, 2016).

Current industrial dryers that are commonly used are inclined bed dryer (IBD), fluidised bed dryer (FBD), re-circulating batch dryer and continuous bed dryer. These designs, despite its useful application, has its own limitation in term of capital and operating cost, the flexibility of processing in small and large scale, and requirement of skilled labour. To produce high-quality rice, not only an efficient and uniform drying are mandatory, the environmental impact of the dryer to the environment and sustainability issue must not be overlooked as well. Existing dryers, although it produces rice of good quality, few complications occurred, and requires some modifications to overcome the issues, which only lead to a higher overall cost.

Flat bed and IBD is a common example of fixed bed dryer which possesses basic designs of paddy's drying technology. This type of dryer consists of perforated sheet floor (bed) with a plenum chamber below it that forced air directly or by the assistance of a duct system (Román et al., 2012). Paddy that is dried using this technology was placed a foot deep as hot air forced to go through the bulk of paddy from below the bed. Currently, IBD is widely used by Padiberas National Berhad (BERNAS) as a second dryer after FBD with the ability to dry grain with high moisture content of 20 - 26 % w.b.(Sarker et al., 2014). The advantages of this dryer are, it is inexpensive compared to the other dryer and have a faster withdrawal of dried paddy. An unskilled labour can operate it as the system is not complicated.

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The drawback reported for this dryer is that it tends to produce unevenly dried product due to inconsistent flow distribution of drying air, which may affect the head rice yield and rice quality. Although this dryer has low energy consumption due to the usage of combustion of biomass as the source of heat, the ashes produced from the biomass burning causes clogging to the filter and the perforated base of the dryer, frequent maintenance and cleaning are necessary. As a result of the direct supply of heat from the biomass combustion to the paddy bed, the output, or the dried paddy tend to be smelly. The hot air used to dry the paddy in IBD are directly discharged to the surrounding, harming the environment and the well-being of the mill's workers.

This paper reports the study on the drying of paddy using LAMB Dryer at ambient temperature. The drying patterns and drying uniformity of the paddy inside the vessel were evaluated by monitoring the changes of the paddy moisture content. The drying uniformity was analysed and compared to other industrial dryers such as IBD.

LAMB dryer is a dryer that is currently under study by a drying team in Universiti Malaysia Sabah (UMS), under the supervision of Dr. Jidon Janaun. LAMB dryer originated from a bioreactor, designed by (Janaun et al., 2007), has its own uniqueness with the perforated vertical tube which allows uniform air distribution. LAMB bioreactor has been used in solid state fermentation on palm kernel cake and the results show that this bioreactor possesses good heat and mass transfer ability, and are able to minimise the residence time for the fermentation to be completed (Wong et al., 2011). The advantages of LAMB in term of uniformity, high mass and heat transfer, as well as the ability to shorten the process time, show the potential of the LAMB bioreactor to be applied as a biomass dryer. The study of 10 kg and 40 kg (Janaun et al., 2016) capacity LAMB dryer has led to the fabrication of commercial scale LAMB dryer, with the capacity of 2 t, currently operating in batch mode in a local rice mill in Kota Belud, Sabah.

The major unit operation for the commercial scale LAMB dryer consists of the LAMB dryer vessel, air heater, blower, conveyor systems, and paddy feeder and withdrawal systems. The schematic diagram of the setup is shown in Figure 1.

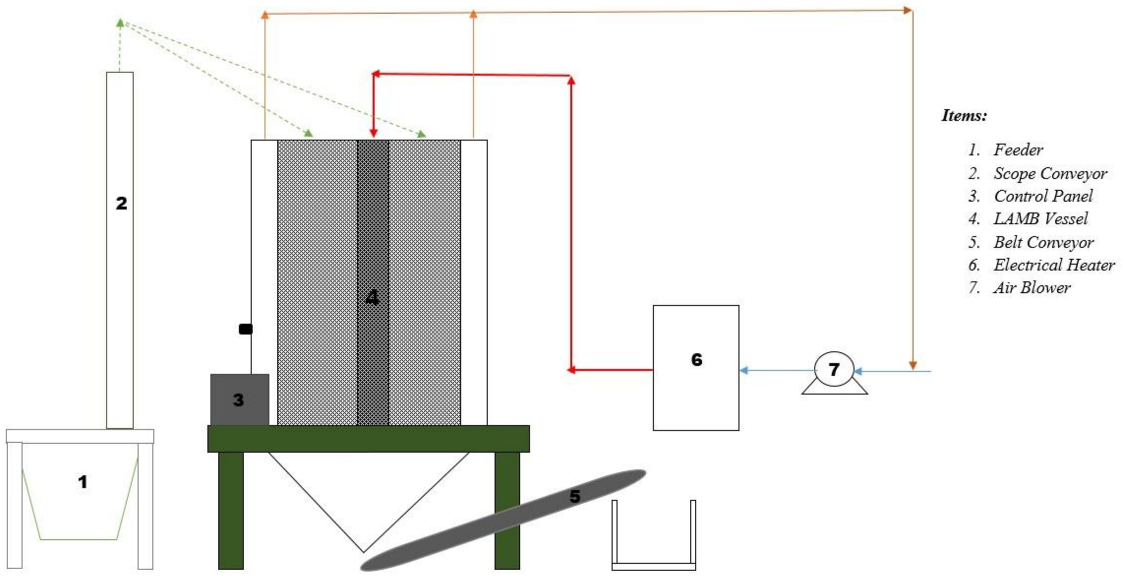

Figure 1: Schematic diagram of the commercial scale Laterally Aerated Moving Bed (LAMB) dryer

Fresh paddy is placed inside the paddy feeder (1). Paddy from the feeder will be transferred into the 4.7 m tall LAMB dryer (4) using a vertical conveyor (2). Air from the LAMB dryer will be sucked by the air blower (7) and sent to the air heater box (6) and then the hot air will be transferred to the LAMB dryer through the upper part of the perforated inner tube. The heating temperature is controlled by a closed-loop temperature control system which uses a thermocouple sensor, whereby the heating capacity of the air heater is adjustable to deliver the desired temperature of the paddy bed monitored by a temperature probe. The system is energy efficient as the hot air was recycled back through the close-loop aeration/air heating system. This minimises the electrical energy consumption since the hot air was recycled back to the heater. The moisture content of the paddy is monitored manually through a sampling port on the LAMB dryer. The dried paddy is withdrawn from the bottom of the LAMB using a mechanical conveyor belt.

Hot air is supplied from the inner tube to the working volume where paddy to be dried will be placed into. The hot air passed through the paddy bed and to the dust collector, the used hot air from the dust collector will be recycled back to the system by passing through the heater and air blower.
The standard mesh was used as the material for the inner tube, the purpose is to ensure the elimination of the existing blind spot that prevents the distribution of hot air into the paddy bed. The perforated inner tube was made up from standard mesh with 3 mm diameter for each perforates that distributed hot air into the LAMB dryer to the paddy bed, and covered the whole 4.7 m length of the inner tube.

2. Experimental Procedure

Freshly harvested paddy of “TQR, TR7, and TR8” varieties, produced in Kota Belud, Sabah region was used in this study. The average initial moisture content of the collected paddy was 17.9 % (w.b.).

2.1 Pre-treatment of Paddy

Paddy sent by the farmers to the mill was weighed and recorded. Before the paddy was loaded into the LAMB dryer’s paddy feeder, it undergone a pre-treatment or screening, in which, the paddy was sieved to separate the rice straws, soils, and stone from the paddy. Screened paddy sent directly into the paddy feeder, and to the LAMB vessel for drying process to take place.

2.2 Drying of Paddy in LAMB Dryer

2 t of freshly harvested paddy with the initial moisture content of 17.9 % (w.b.) was loaded into the LAMB dryer after undergoing the screening process. The temperature of the heater was set to be at ambient (30 - 35 °C) and both the heater and blower was switched on. Samples of paddy were retrieved from the sampling point located at approximately 0.8 m from the base of LAMB vessel at every 1 h interval. The moisture content of approximately 3 g of the samples was analysed using moisture analyser Sartorius MA 35 and samples that possess more than 14 % MC was considered not dry. Hot air was continuously blown throughout the paddy bed for 5 h and undergoes tempering for 1 h. Samples retrieved from the sampling port at every 1 h intervals were analysed and the analysis was duplicated.

2.3 Withdrawal of Paddy in LAMB Dryer

At the end of the experiments, the 2 t paddy was withdrawn from the LAMB vessel as sample was retrieved at approximately every 300, 600, 900, 1,200, 1,500, 1,800, and 2,000 kg of the withdrawn paddy. The MC of an approximately 3 g of the retrieved sample was analysed using the moisture analyser Sartorius MA 35.

3. Results and Discussion

3.1 Drying Pattern of Paddy

Based on the study, the drying pattern of paddy was determined at drying condition of ambient (30 - 35 °C) drying temperature, fixed air flowrate (530 m^3/h), 5 h heating time and 1 h tempering time.
Figure 2 shows the drying kinetics of the commercial scale LAMB dryer. From t = 0 h to 2 h, the average MC of paddy decreases from 17.87 ± 0.64 to 14.36 ± 1.59 %. The MC kept on decreasing further, slightly to 13.74 ± 1.39 and 13.04 ± 2.65 at t = 4 h and 5 h, which was almost constant. This can be closely related to the moisture diffusivity and the structure of the paddy grain itself. In the first 3 h, the moisture at the surface (or also known as the surface moisture) was dried by the air, and the saturated moisture at the centre of the kernel diffused slowly to the surface, hence causes such results at t = 4 h and 5 h, where there was an insignificant or almost no moisture on the husk surface to be absorbed and carried by the passing air. Past work shows that the inner diffusion of paddy limits the drying rate determination (Rao et al., 2007) . The moisture content analysis demonstrated a reduction of 1-point percentage from t = 5 until it reaches 12.04 % MC at t = 6 h, where tempering was performed.
The tempering process resulted in a very low moisture reduction due to the lower temperature (ambient) applied during tempering. Tempering performed at lower temperature, below the glass transition temperature line gave an insignificant effect on the rice (Cnossen and Siebenmorgen, 2000). However, Dong et al. (2010) suggested that proper tempering conditions may be applied to eliminate moisture gradient and assist in minimising broken kernel due to severe drying. The results of the experiment, however, showed a slight reduction at t = 5.5 h and an increment at t = 6 h. Previous studies reported that the moisture at the surface of the kernel was carried by air and during tempering, the MC at the centre of the grain migrates to the surface, causes the MC at the surface to increase (Dong et al., 2009).

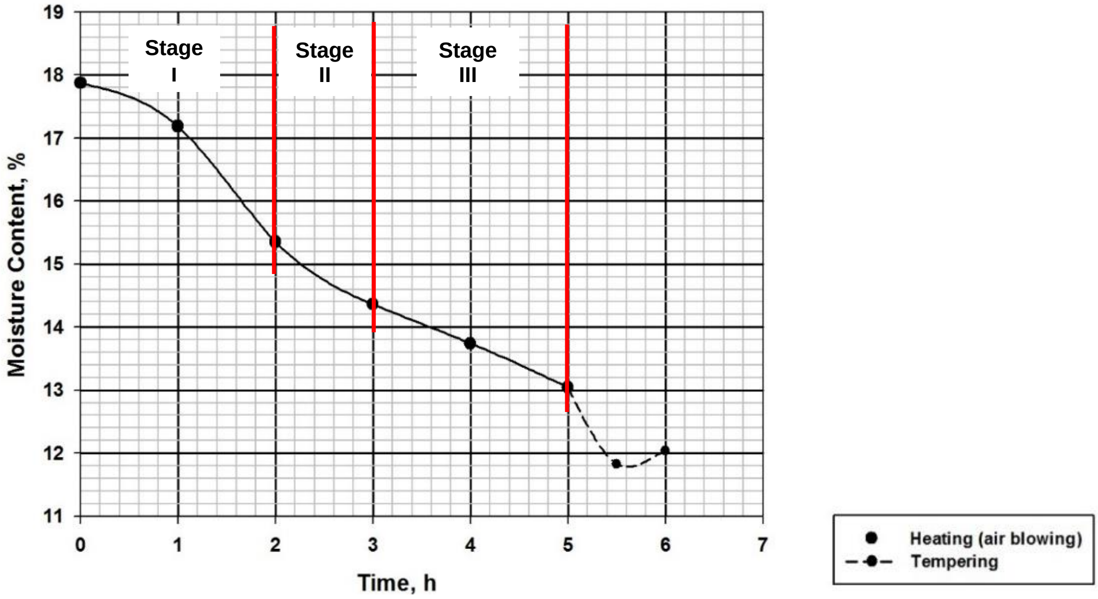

Figure 2: Drying pattern of paddy in Laterally Aerated Moving Bed (LAMB) Dryer, 5 h heating and 1 h tempering (Temperature: 30 °C, Air flowrate: 530 m^3/h, Z: 8.8)

There are three stages involved in the paddy drying curves in Figure 2. The first stage is the rapid moisture removal from the rice husk, which occurred from t = 0 h until t = 2 h. This proves that the moisture diffusion rate is faster from the husk to the air than from the starchy endosperm to the husk, in agreement with the studies conducted by (Rao et al., 2007). The second stage that can be determined from the drying plot is the transition state in which the dynamic diffusion of moisture from starchy endosperm into the bran, and further to the husk. At the end of stage one, the surface moisture is almost zero, constant until the moisture from within the kernels starts diffusing to the husk for desorption, resulting in a dynamic state before the final stage occurred. In this stage, it ranges from t = 2 h up to t = 3 h. The final stage is the steady state drying, occurring from t = 3 h up to 5 h, right before tempering started. In this stage, the moisture diffuses from within the paddy and from the surface to the surrounding is reaching its steady-state condition. The moisture from within the grain travels to the surface, driven by the moisture gradients and this desorption process will last until the process has reached moisture equilibrium.

3.2 Drying Uniformity of Paddy in LAMB Dryer

Figure 3 shows the moisture content of paddy in the LAMB vessel at specific height. The variation of dryness in Figure 3 shows that MC of the paddy at the bottom part (height, H = 0.5 m) of the LAMB vessel are lower (10.26 % w.b.) than that situated at the top. It can be seen that the MC of paddy inside the vessel kept on increasing with height up until H = 1.972 m (16.68 % w.b.), and started declining once more when it reached H = 2.519 m until H = 3.455 m. The MC of the paddy at the top of the LAMB dryer, H = 4.063 m however, are higher. From the plot, it can be deduced that the drying uniformity of paddy inside the vessels is fluctuating.
The summaries of the result are:
Average final moisture content (w.b %) : 13.77 ± 2.23 w.b.%
Percentage Standard Deviation (% SD) for horizontal variation : 2.93 %
Percentage Standard Deviation (% SD) for vertical variation : 16.94 %
It can be seen that the uniformity in vertical variation shows a high standard deviation percentage (16.94 %), and the horizontal analysis shows 2.93 % which is high as compared to the International Rice Research Institution (IRRI) standard of ±1.00 % w.b., showing that the current performance of LAMB dryer is still below the desired target. However, the LAMB dryer's uniformity is much better compared to other dryer such as IBD, which shows a deviation as high as ±3.03 % w.b. This uneven moisture distribution was probably contributed by the impurities existed and the different paddy species used in the paddy bed as reported by (Prakash and Pan, 2012).

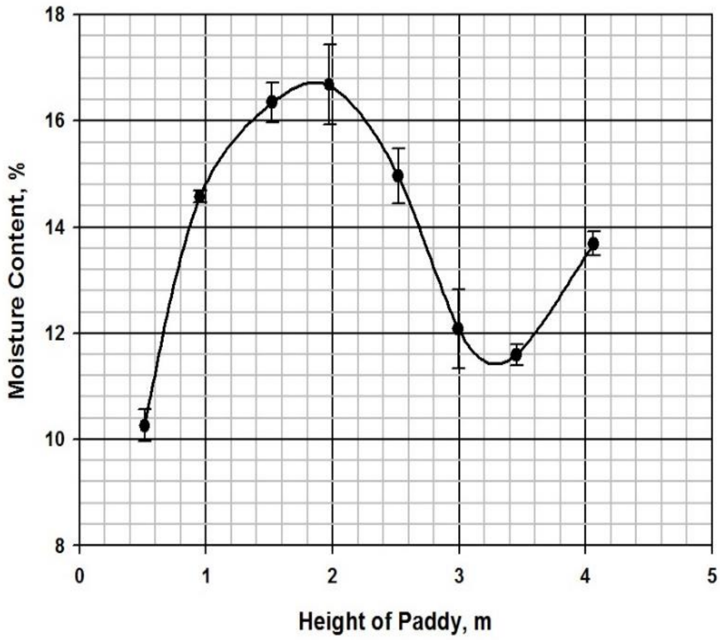

Figure 3: Drying uniformity of paddy in LAMB vessel based on height

The differences between the dryness at the bottom and the top of the LAMB vessels shown in Figure 3 is likely caused by the Bernoulli's effect, in which high pressured hot air blown in the inner tube forces the air to dispersed faster at the bottom part, resulting in the paddy at the bottom part of the LAMB vessels to be drier than the top part.

4. Conclusions

A commercial scale LAMB dryer was designed and fabricated, and tested by a local rice mill in Kota Belud, Sabah, Malaysia. The LAMB dryer was used to reduce the moisture content of freshly harvested paddy to a desired level before the paddy is dehusked. The drying of paddy in LAMB dryer was affected by aeration temperature, aeration flow rate and the residence time. The operation of LAMB dryer at ambient aeration temperature for 6 h showed promising results. The vertical variation had a standard deviation of 16.94 %, whereas the horizontal variation showed a standard deviation of 2.93 %. These results were close to the recommended SD% by IRRI. The performance of LAMB dryer indicated better drying duration compared with the conventional IBD used by the local rice mill. More experiments are in progress to optimise the operation of LAMB dryer.

Acknowledgments

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