DRYING OF PADDY IN A COMMERCIAL SCALE LATERALLY AERATED MOVING BED (LAMB) DRYER

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FACULTY OF ENGINEERING
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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries and references, which have been duly acknowledged.

25 SEPTEMBER 2018

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ABSTRACT

Drying is a critical part in processing industries such as rice production. Many dryers have been invented but they are all having limitation in terms of effectiveness, efficiency, and sustainability. A novel industrial dryer has been developed called Laterally Aerated Moving Bed (LAMB) Dryer in Universiti Malaysia Sabah. Small scale LAMB dryers were shown to be effective and efficient, however, its applicability in commercial scale has not been ascertained. Hence, this study investigates the scale up design of LAMB dryer with a capacity to dry 2000 kg paddy, fabricate and test it. The scale up strategy involved the utilization of dimension factors used in small LAMB dryers (10 and 40kg capacities) and also intuition as computer simulation was not accessible. The fabrication was outsourced to a local contractor which runs a rice mill business. After troubleshooting and commissioning were completed, the effectiveness and efficiency of the commercial scale LAMB dryer were evaluated by varying the process temperature and also the tempering time, while the air flowrate was fixed. The rice quality was analysed to ascertain the applicability of LAMB dryer in actual commercial operation. The scope of this study includes evaluating the effectiveness and efficiency of a conventional dryer used by the rice mill called Inclined Bed Dryer (IBD), a comparison between LAMB dryer and IBD was presented. The results showed that the drying rate of paddy in LAMB dryer was higher, which was 0.53%/hr-1.0%/hr compared to 0.22%/hr in IBD. The drying rates in the LAMB dryer showed that moisture removals in LAMB was faster and resulted in shorter drying duration (8-16 hours). The drying air penetration shows a uniform flow along the heights, the MC at the bottom and middle part shows a steady reduction with time while the top part has a very small to none reduction due to the temperature at the top being lower compared to the bottom. The RH of paddy for both bottom and middle part shows a gradual reduction with MC, and the drying process usually ended when the RH reading reached 40%. RH at the top part on the other hand, fluctuated about the same range (90-99%), with the temperature lower than the set point. The rice quality analysis showed that drying at 45^{o}C with tempering in LAMB dryer produced higher head rice yield (HRY) (80-81.5%) compared to the rest of experiments, the rice colour analysis were comparable among all the samples. In conclusion, this work demonstrated that the commercial scale LAMB dryer worked effectively and efficiently in paddy drying applications and has a great potential to be commercialized.

ABSTRAK

PENGERINGAN PADI MENGGUNAKAN LATERALLY AERATED MOVING BED (LAMB) DRYER BERSKALA KOMERSIL

Pengeringan adalah bahagian penting dalam industri seperti pengeluaran beras. Banyak pengering telah dicipta tetapi mereka semua mempunyai batasan dari segi keberkesanan, kecekapan, dan kemampanan. Sebuah pengering industri baru telah dibangunkan yang dikenali sebagai Dryer Bed Moving Laterally (LAMB) di Universiti Malaysia Sabah. Pengeringan LAMB berskala kecil ditunjukkan dengan berkesan dan cekap, namun penggunaannya dalam skala komersial belum dipastikan. Oleh itu, kajian ini menyiasat reka bentuk skala pengering LAMB dengan kapasiti kering 2000 kg padi, membuat dan mengujinya. Strategi mereka bentuk LAMB komersil melibatkan penggunaan faktor-faktor dimensi yang digunakan dalam pengering LAMB kecil (10 dan 40kg kapasiti) dan juga intuisi kerana simulasi komputer tidak dapat diakses. Fabrikasi itu dipertanggungjawabkan kepada kontraktor tempatan yang juga menjalankan perniagaan beras. Setelah penyelesaian masalah dan pentauliahan selesai, keberkesanan dan kecekapan pengering LAMB skala komersial telah dinilai dengan memvariasikan suhu proses dan juga masa pembajaan, aliran udara adalah tetap. Kualiti padi dianalisis untuk memastikan penggunaan pengering LAMB dalam operasi komersial yang sebenar. Skop kajian ini telah diakhiri dengan menilai keberkesanan dan kecekapan pengering konvensional yang digunakan oleh kilang padi yang dipanggil Inclined Bed Dryer (IBD), perbandingan antara pengering LAMB dan IBD dibentangkan. Keputusan menunjukkan bahawa kadar pengeringan padi dalam pengering LAMB lebih tinggi, iaitu 0.53% / hr-1.0% / hr berbanding dengan 0.22% / jam dalam IBD. Kadar pengeringan di pengering LAMB menunjukkan bahawa penyingkiran kelembapan dalam LAMB adalah lebih cepat dan menyebabkan tempoh pengeringan yang lebih pendek (8-16 jam). Penembusan udara pengeringan menunjukkan aliran seragam sepanjang ketinggian, MC di bahagian bawah dan pertengahan menunjukkan pengurangan yang mantap dengan masa sementara bahagian atas mempunyai pengurangan yang sangat kecil hingga tidak ada kerana suhu yang lebih rendah berbanding bahagian bawah . RH padi untuk bahagian bawah dan pertengahan menunjukkan penurunan secara beransur-ansur dengan MC, dan proses pengeringan biasanya berakhir apabila bacaan RH mencapai 40%. RH di bahagian atas sebaliknya, bervariasi pada julat yang sama (90-99%), dengan suhu lebih rendah daripada titik set. Analisis kualiti padi menunjukkan bahawa pengeringan pada suhu 45^{o}C dengan pengeringan dalam pengering LAMB menghasilkan hasil beras yang lebih tinggi (HRY) (80-81.5%) berbanding dengan eksperimen lain, analisis warna padi adalah sebanding dengan semua sampel. Kesimpulannya, kerja ini menunjukkan bahawa pengeringan LAMB skala komersil bekerja dengan berkesan dan cekap dalam aplikasi pengeringan padi dan mempunyai potensi besar untuk dikomersialkan.

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LIST OF ABBREVIATIONS

%SD	Percentage Standard Deviation
%w.b.	Wet basis percentage
EMC	Equilibrium Moisture Content
ERH	Equilibrium Relative Humidity
FBD	Fluidized Bed Dryer
HRY	Head Rice Yield
IBD	Inclined Bed Dryer
IMC	Initial Moisture Content
LAMB	Laterally Aerated Moving Bed
L*a*b	Color Scale L: white-dark a*: green-red b*: blue-yellow
MC	Moisture Content
RH	Relative Humidity
SBD	Spouted Bed Dryer

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CHAPTER 1

INTRODUCTION

Overview Thesis Organization

The first part of this thesis chapter starts with chapter 1; Introduction. This chapter focuses on the introductory part of the thesis, comprises the motivation and research purpose such as the problem statements, novelty of the study, research scope, hypotheses and research objectives. The second part of the thesis is the chapter 2: literature review, explains about the relevant literatures that other researchers is currently or has worked on. It covers the literature from industrial dryers and paddy drying process, as well as the conditions affecting the rice quality. Chapter 3 consists of steps to achieve the research objectives. It covers the scale up design of LAMB dryer from lab scale to commercial scale, fabrication, commissioning, testing and analysis on the end product quality as well as the feasibility study and also a brief description on the working principles of the instruments used in this study. Chapter 4 emphasizes on the details discussion of the obtained results from the scale up and design process, commissioning, testing of the dryer, and rice quality analysis. Last but not least, in chapter 5 summarized the overall thesis study in conclusions and recommendations.

1.1 Research Background

Present rice industry implements the use of mechanical dryers to shorten the process time to dry fresh wet paddy. In ancient time, the uses of sun drying are popular yet time-consuming. It requires as long as 3 days with sun radiation to completely dry a paddy to its 'safe' level. Due to the increasing demand and feed stocks, dryers were developed to assist in the drying process. These incentives to develop mechanical dryers were also carried out to reduce food wastage from deteriorating products.

In grain processing, a freshly harvested grain usually contain up to 35% (w.b.) moisture content. The presence of excess water promotes the microbial activity that causes food spoilage and decay. Hence, grain must be dried to about 13% (w.b.) moisture for safe, and prolonged storage (Geankoplis, 2003). Despite the numbers of dryers that exist the in industry, the increasing demand of rice requires the industry to minimize the losses that occurred during the post-harvest process. Substantial post-harvest losses, particularly in drying process ranging from 1 to 5%, proves that the current drying technique is incompetent (FAO Corporate Documentary Repository, 2002).

A large amount of grain requires rapid drying to prevent microbial infection (i.e. to preserve the grain), rapid drying requires high-temperature drying. However, high-temperature air shows a contribution in the depletion of rice quality during milling due to thermal cracking and stresses, as well as moisture re-absorption. Serious damage towards the grain was recorded over the time of drying process when using high-temperature, although it assists in rapid drying.

Current industrial dryers that are commonly used are inclined bed dryer (IBD), fluidized bed dryer (FBD), recirculating 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 labor. 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.

Hence, a new technology dryer that has the ability to produce good rice quality, energy efficient and an environment-friendly dryer is a necessity. A study is required to determine the optimum drying condition which can minimize the damage upon the quality of the grain, with minimal cost operation, and impact to the environment.

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 analyzed and compared to other industrial dryers such as IBD.

The novel "Laterally Aerated Moving Bed (LAMB)" was categorized in the "Moving Surface" category, and is a type of multiphase reactor. The designed LAMB possesses a perforated vertical inner tube which promotes radial aeration that advocates uniform air distribution throughout the tube. The initial study of LAMB is from the Laterally Aerated Moving Bed Reactor in solid-state fermentation. (Wong, Saw, Janaun, Krishnaiah, & Prabhakar, 2011) shows that the LAMB bioreactor produced good heat and mass transfer, as well as reduces the fermentation period.

The features shown by the LAMB from the study prove that the LAMB has potential to be turned into a good biomass dryer.

A trial on lab scale (10kg and 40kg capacity) LAMB dryer has also shown a good performance although further detailed studies are necessary, to transform and revamp these lab scale LAMB dryers for industrial use, and necessary modification and adjustment need to be made to meet the process requirement.

1.2 Problem Statement

The increasing populations contributes to the increasing demand for foods, in Asia for instance, the increment of paddy production increases from 41 kt on 2014 to 12.9 Mt in 2015/2016 (Wahab, 2016), this is also recorded by the Department of Statistic Malaysia in 2015. The limitations of the existing paddy dryers caused researcher to participate in improving the dryers and its systems. For instance, the Inclined Bed Dryer (IBD) used by a local paddy mill in Sabah experienced losses in each process, and the drying process took a very long time to dry a batch of paddy. In addition, the mill's drying unit also required frequent maintenance due to the ashes produced from the rice husk powered furnace, clogging the piping system. Study on the lab scale LAMB dryers has shown that LAMB dryer has advantages in term of uniformity, high mass and heat transfer, as well as its ability to shorten the drying durations. However, the capability of the commercial scale LAMB dryer to dry paddy and to maintain the similar drying characteristics with the lab scale's, has yet to be discovered.

1.3 Research Novelty

LAMB is known to possess a high capability in heat and mass transfer, low energy consumption, and its application in solid state fermentation reduces the fermentation period significantly (Wong et al., 2011), with a novel drying technique and working principle. However, its potential in paddy drying has yet to be investigated, especially in a larger scale. In this study, a single-tube commercial scale LAMB dryer will be scaled-up, design and fabricate, and it is the first of its kind to be applied in paddy drying.

1.4 Hypothesis

Drying of grain materials at lower temperature are said to significantly increase its quality, however, requires longer time. It is hypothesized that the commercial scale LAMB dryer is able to shorten the residence time to complete a drying process with better rice quality with the provided air distributor or inner tube. This can be achieved by using a sufficient temperature, and the uses of the right drying method. It is also hypothesized that the moisture content (MC) of paddy is closely related to its relative humidity (RH), and that the dryness of paddy can be correlated and determined by its RH value.

1.5 Research Objectives

The main objectives of the research are:

i. To design and fabricate the scaled-up LAMB dryer and its full system
ii. To perform commissioning, troubleshooting, and testing of LAMB dryer
iii. To compare the paddy drying using LAMB dryer and Inclined Bed Dryer (IBD)
iv. To determine the curve-fitting of RH-MC, and to model the paddy drying in LAMB
v. To analyse and compare the rice quality produces by LAMB dryer and IBD

1.6 Scope

The research scope covers the design and scale-up process of LAMB dryer from 40kg capacity, to 2000kg capacity through a number of steps, where a series of studies will be performed to gain required information such as the dryer's workability, kinetics and the outcomes of its produces. The parameters involved in this research include temperature, tempering and relative humidity, to study its effects in the drying rate and quality. Next, the air flow inside the LAMB dryer with and without load will be investigated to study the flow pattern of drying air in the vessel. Apart from that, the relationship between the moisture reduction of paddy and its relative humidity will be established so that in the future, process completion of paddy drying can be determined using the relative humidity reading instead.