
**UNIVERSITI PUTRA MALAYSIA**

***DRYING PERFORMANCE OF INCLINED BED DRYER WITH AIR FLOW REVERSAL AND ITS EFFECTS ON RICE MILLING QUALITY***

**MARYAM GHIASI**

# DRYING PERFORMANCE OF INCLINED BED DRYER WITH AIR FLOW REVERSAL AND ITS EFFECTS ON RICE MILLING QUALITY

**By**

**MARYAM GHIASI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science**

**October 2016**

**DEDICATION**

This thesis is dedicated to my lovely parents, Mahnaz Bakhshizadeh and Vahid Ghiasi, who taught me the value of education. I am deeply indebted to them for their endless love, encouragement, and unwavering faith in me. It is also dedicated to my best friend Zeinab for her support, prodding and being a wonderful company during my study.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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**Chairman : Associate Professor Mohd Nordin Ibrahim, PhD**
**Faculty : Engineering**

Drying rice grains to a safe moisture content is always a critical issue in humid tropical countries such as Malaysia. Observations show that conventional drying with flat and inclined-bed dryers are the most common drying practices in Malaysian rice processing industry. Many studies evidently proved that due to inappropriate set of drying conditions and also profound moisture and temperature gradients inside grain bed, these dryers produce rice with relatively low and also non-uniform milling quality. Besides, less satisfactory drying efficiency associated with energy consumption and drying capacity were observed for these popular fixed-bed dryers. Thus the first main objective of this study was to investigate on optimum drying condition for rice drying with flat and inclined bed dryers in order to ensure maximum drying efficiency and rice milling quality. In addition, single and periodic air flow reversal techniques in conjunction with one stage and two stage drying were introduced in order to improve rice drying performance. To carry out this study, laboratory flat-bed and inclined-bed dryers were designed and fabricated based on industrial dryer conditions. Drying experiments were carried out with different variations of air flow reversal, bed depth and temperature. Consequently, the effects of all drying experiments on drying performance, drying capacity, energy usage, and rice milling quality were evaluated. Results revealed that although both dryers produced rice within acceptable milling quality range but inclined-bed dryer showed significantly better performance in terms of throughput capacity and energy consumption compared to flat-bed dryer for all applied temperatures. Furthermore, comparative analysis results between conventional and one stage air flow reversal drying showed that changing the direction of air flow during drying operation had phenomenal effects on rice milling quality. Head rice yield percentages were improved by 21.08% with triple air flow reversal for 50cm bed depth and 17.53% with twice air flow reversal for 75cm bed depth compared to common drying practice. Moreover, air flow reversal drying technique remarkably improved drying capacity by 18% to 55% compared to conventional drying. This technique also had great potential to minimize the electrical energy usage by reducing 11%, 12% and 43% of energy required for drying 50cm, 75cm and 100cm rice bed depths respectively compared to

existing industrial drying method in Malaysia. Findings also indicated that reducing the bed depth had dominant effects on head rice yield, rice whiteness degree and energy efficiency of drying operation. Finally, findings showed that when periodic air flow reversal was applied in two stage drying, the excellent milling quality of almost 70%, the highest throughput capacity of 0.037 ton $m^{-2}$ $h^{-1}$ and also the lowest specific electrical energy consumption of 91.93 kWh $ton^{-1}$ were achieved. Therefore, air flow reversal technique combined with one and two stage drying can be strongly recommended to rice industries as applicable and effective options for improving rice milling quality and overcoming low efficiency of existing drying operations.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**PRESTASI PENGERINGAN BAGI PENGERING PELANTAR CONDONG DENGAN PEMBALIKKAN ALIRAN UDARA DAN KESANNYA KEATAS KUALITI BERAS.**

Oleh

**MARYAM GHIASI**

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Pengeringan bijirin padi kepada suatu kandungan kelembapan selamat adalah senantiasa isu kritikal di negara tropikal seperti Malaysia. Pemerhatian menunjukan bahawa pengeringan konvensional dengan pengering lapisan datar dan condong adalah amalan paling biasa dalam industri pemprosesan beras di Malaysia. Banyak kajian telah menunjukan dengan jelas bahawa disebabkan oleh keadaan pengeringan tidak wajar, dan juga cerun suhu dan kandungan kelembapan yang menyerlah dalam lapisan bijirin, pengering ini menghasilkan mutu pengilangan beras yang rendah dan tidak seragam. Juga, kecekapan pengeringan berkaitan dengan kegunaan tenaga dan keupayan pengeringan yang kurang memuaskan telah terdapat pada pengering di gemari ini. Oleh itu tujuan utama pertama kajian ini adalah menyiasat keadaan pengeringan optimum untuk mengering padi dengan pengering berlapisan datar dan condong bagi memastikan kecekapan pengeringan dan kualiti pengilangan beras yang maksimum. Bagi melaksanakan kajian ini, pengering lapisan datar dan condong telah direka bentuk dan dibangunkan di dalam makmal berasaskan keadaan pengeringan industri. Eksperimen pengeringan telah dijalankan dengan perubahan berlainan bagi aliran udara teralih, kedalaman lapisan dan suhu. Seterusnya, kesan semua experimen pengeringan keatas perlakuan pengeringan, keupayaan pengeringan, penggunaan tenaga dan mutu pengilangan beras telah dinilai. Keputusan mempamirkan bahawa walaupun kedua2 pengering menghasilkan beras dengan kualiti yang boleh diterima, tetapi pengering lapisan condong memperlihatkan perlakuan yang lebih baik berkaitan keupayaan muatan dan penggunaan tenaga untuk semua suhu yang digunakan. Lebih2 lagi keputusan analisa perbandingan diantara pengeringan kovensional dan pengeringan satu peringkat dengan aliran udara teralih menunjukan bahawa menukar arah aliran udara semasa operasi pengeringan memberi kesan sangat memberansangkan keatas kualiti pengilangan beras. Hasil kepala beras di tingkatkan dengan 21.08% dalam pengeringan dengan aliran udara teralih tiga kali pada ketebalan lapisan 50 sm, dan 17.53% dalam pengeringan dengan aliran udara teralih dua kali pada ketebalan 75sm berbanding dengan amalan pengeringan biasa. Tambahan pula, teknik pengeringan aliran udara

teralih boleh tingkatkan keupayaan muatan pengeringan 18% hingga 55% berbanding dengan pengeringan konvensional. Teknik ini ada potensi terbaik untuk meminimumkan pengunaan tenaga letrik dengan mengurangkan 11%, 12% dan 43% tenaga yang diperlukan bagi mengeringkan lapisan padi 50sm, 75sm dan 100sm berbanding dengan kaedah pengeringan industri tersedia di Malaysia. Penemuan juga menunjukan bahawa mengurangkan kedalaman lapisan padi di dalam pengering telah memberi kesan besar keatas hasil kepala beras, darjah keputihan beras dan kecekapan tenaga bagi operasi pengeringan. Akhirnya, penemuan menunjukan bahawa apabila aliran udara teralih berjangka diguna dalam pengeringan dua peringkat, kualiti pengisaran beras terbaik menghampiri 70%, keupayaan muatan yang tertinggi 0.037 ton $m^{-2}$ $h^{-1}$ dan juga penggunaan tenaga letrik spesifik yang terendah 91.93 kWh $ton^{-1}$ telah diperolehi. Oleh itu, teknik aliran udara teralih berganding dengan pengeringan satu dan dua peringkat boleh di cadangkan dengan tegas kepada industri padi/beras sebagai pilihan berguna dan berkesan untuk meningkatkan mutu pengilangan beras dan untuk mengatasi kecekapan rendah dalam operasi pengeringan padi tersedia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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**Declaration by Members of Supervisory Committee**

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| A | Original dried rice mass | g |
| B | Head/whole rice kernel mass | g |
| d.b | Dry basis moisture content | - |
| DOM | Degree of milling | % |
| $E_b$ | Electrical energy consumption of blower | kWh |
| $E_h$ | Electrical energy consumption of heater | kWh |
| $E_t$ | Total electrical energy consumption of dryer | kWh |
| FAO | Food and agriculture organization | - |
| FBD | Flat-bed dryer | - |
| FMC | Final moisture content | w.b |
| HRY | Head rice yield | % |
| HT | High temperature drying | - |
| IBD | Inclined-bed dryer | - |
| IRRI | International rice research institute | - |
| LT | Low temperature drying | - |
| MC | Moisture content | w.b |
| $MC_f$ | Final moisture content | d.b |
| $MC_i$ | Initial moisture content | d.b |
| NFA | National Food Authority | - |
| PHilMech | Philippine centre for postharvest development and mechanization | - |
| RH | Relative humidity | % |
| SPEEC | Specific electrical energy consumption | kWh $ton^{-1}$ |
| T | Temperature | ℃ |
| t | Time | hours |
| W | Total weight of wet rice | ton |
| w.b | Wet basis moisture content | - |

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Rice (Oryza sativa L.) is one of the leading food crop in the world which consumed by half of the world population (Bunyawanichakul et al., 2007; Tirawanichakula et al., 2004a). Drying of this popular grain is always a crucial issue in rice producing countries especially with humid tropical climates such as Malaysia. Because, in this unfavourable weather condition rice is harvested with relatively high initial moisture content of 20-25%. (w.b) (Igathinathane *et al*., 2008; Inprasit and Noomhorm, 2001). Grains with high moisture content are subjected to serious quality deterioration after harvesting (Ahmed *et al*., 2006). Thus drying rice down to safe moisture content of 12-14% in suitable time plays an important role in providing high quality rice for long term storage. Moreover, inappropriate or ineffective set of drying conditions, drying methods and also dryer's type have dominant effect on rice quality and energy consumption of any drying process (Champagne, 2004). Since actual need of population for milled rice is increasing each year, improving grain quality through sufficient drying process is always the major concern of rice producers. It is noted that head rice yield (HRY), whiteness degree and degree of milling (DOM) are the main standards indicators of rice milling quality.

Although numerous drying options have been introduced by researchers to produce high quality product but observations revealed that Asian rice producers still prefer to use conventional drying (one stage and one direction of air flow) with traditional fixed-bed dryers in form of flat-bed dryer (FBD) and inclined-bed dryer (IBD) (Tajaddodi, 2012; IRRI, 2012). Figure 1.1 shows industrial IBD and FBD which commonly used by rice industries.

**Figure 1.1: Common Industrial IBD (left side) and FBD (right side)**
(Source: PHilMech, 2008)

Generally, non uniform distribution of temperature and moisture content inside the product bed are common characteristics of fixed batch dryers. Obviously grain at bottom layer of dryer expose to high temperature inlet air more than grains at upper layers. As a

result, over drying in bottom grains and moisture absorption at middle and top sections of grains bed will be observed normally in this type of dryers (Golmohammadi *et al*., 2015; Tajaddodi, 2012; IRRIa, 2011). Sarker *et al.* (2014) stated that rice kernels with extremely low moisture content are weak and may break easily after drying process. Researches also revealed that moisture absorption phenomena may develop fissuring in rice kernels which will increases the rice breakage during and after milling process (Kunze, 2008). Therefore, duo to mentioned reasons, milling quality of rice grains produced by fixed bed dryers is expected to be relatively low and non-uniform. Rice Knowledge Bank (2010) stated that Asian rice industries produce rice with 35 to 50 percentage of head rice yield. Actual observation of industrial rice dryers also revealed that white rice produced with maximum 50% head rice yield (third grade milled rice) in Malaysia (Sarker, 2014; NFA 2016). It means, more than half of total milled rice mass did not have the trade value of whole rice and also could not be considered for exporting purposes. Researches stated that improving head rice yield even by one percent can save great amount of rice which will lead to significant incensement in annual income of this popular industry (Tajaddodi, 2012; NFA 2016). Beside quality aspects, studies indicated that fixed-bed drying of rice is long time operation which consumed great amount of energy (Sarker, 2014; Tajaddodi, 2012; Tirawanichakul *et al*., 2004a). As a result, overall efficiency of this popular industrial rice dryer appear to be relatively low, regarding capacity and energy consumption of drying operation. Since energy carrier cost have risen drastically in recent years, rice producers are confronting with serious issue. Since economic value of rice directly determine by rice milling quality, finding effective and applicable drying practices with existing fixed-bed dryers in order to improve rice milling quality could be economically beneficial for rice industries. Moreover, maximizing drying capacity and minimizing energy usage of drying process are other concerns of rice producers to reduce their production costs.

Some researchers introduced air flow reversal technique in conjunction with conventional drying as a potential way to produce high quality grain such as coffee soybeans and maize (IRRIb, 2011; Berbert *et al*., 1995; Berbert *et al*., 1994; Davilia, 1983). They stated that significant reduction in moisture content gradient were observed when air flow direction reversed during drying compared to conventional (one direction) drying. As a result of less moisture differences through the grain bed, quality of final product increased by air flow reversal technique. In is noted that in this proposed method, grains at both end of dryer bin have the same opportunity to be in contact with fresh inlet air at least one or more than one times during drying operation which is called single and periodic air flow reversal drying respectively. Recently Ibrahim *et al*. (2013) study single air flow reversal drying on rice with flat-bed dryer. They also stated that higher milling quality rice was produced by less energy cost when single air flow reversal drying was conducted compared to conventional rice drying. They also suggested that further work is required to study different aspects of periodic or periodic air flow reversal method of rice drying.

Two stage drying strategy is another feasible method that have been proposed for producing high quality grain with high initial moisture content in shorter drying time such as corn, wheat and rice (Jittanit *et al*., 2010; Srzednicki and Driscoll, 2008; Thakur and Gupta, 2006). Results of these studies also revealed that stage drying have great effects on capacity and energy consumption of drying operation. In this technique, first

stage is carried out with high temperature inlet air in order to rapidly reduce the moisture content of grains to more manageable level. Subsequently air with low temperature would be used in second stage of drying to remove moisture from inner part of grains to final moisture content. This method is being practiced lately in many countries like Thailand, Philippine, Taiwan, Indonesia and Malaysia by using fluidized bed, spouted bed, and Louisiana State University (LSU) dryers for first-stage and fixed-bed dryer, ambient air ventilation or sun-drying methods in second stage of drying process (Sarker *et al*., 2013). Although two stage drying can bring great advantages for drying industries but due to inadequate knowledge about high temperature operation technique and also high cost of purchasing high temperature dryer (such as fluidized bed dryer), one stage drying is still preferred by Malaysian rice manufactures (Sarker *et al*., 2013).

Whilst the demand for high quality rice is raising by increasing world population but observation revealed that producing rice grains with moderate to low milling quality is still a serious issue in Malaysian rice industries. Moreover this industry found not to be concerned enough about the importance of energy saving in recent years. Also very few publications appeared in literatures which focused on energy consumption and capacity of rice drying practices. Thus it is essential to introduce suitable and feasible drying options to improve rice milling quality and overall efficiency. Otherwise all efforts have been done to increase rice productivity will be simply thrown away.

## 1.2 Main Goals of Study

Present work aimed to study the drying performances of FBD and IBD with common drying conditions in order to guide Malaysian rice industries to optimize their existing drying system. Furthermore, the possibility of improving rice milling quality and drying efficiency by application of air flow reversal method in conventional fixed-bed drying was investigated in this study. In addition, air flow reversal technique in conjunction with two stage drying have been conducted as a third objective in order to comprehensively study the effect of high temperature drying on different aspects of producing rice. Findings could guide rice industries to achieve better quality rice at reasonable energy usage by conducting simple modification in their drying operations.

## 1.3 Specific Objectives

The specific objectives of present study could be summarized as follows:

1. To determine the drying performances of conventional drying with FBD and IBD in two industrial ranges of temperature (38-39℃ and 42-43℃) based on drying capacity, energy usage and milling quality of rice.
2. To study the effects of single and periodic air flow reversal methods with IBD at selected bed depths (100, 75 and 50cm) on rice milling quality and also drying efficiency.
3. To investigate air flow reversal technique combined with two stage drying of IBD regarding rice milling quality, drying capacity and energy consumption.

## 1.4 Thesis Outline

This thesis consists of six chapters. Introduction and objectives are presented in first chapter. Second chapter is the survey of literature and gives information about rice drying concepts, rice drying strategies including air flow reversal and two stage drying, and importance of rice quality and drying efficiency for rice industries. The overall experimental procedures for this study are presented and discussed in chapter three. Evaluation of air flow reversal and two stage drying techniques based on temperature and moisture profile, rice milling quality, drying capacity, and drying energy consumption are focused in chapter four. Finally, the conclusion of this study and recommendations for future works are presented in chapter five.

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## LIST OF PUBLICATIONS

### Published

**M. Ghiasi**, M.N. Ibrahim, R.K. Basha, R.A. Talib. Energy usage and Drying Capacity of Flat-bed and Inclined-bed Dryers for Rough Rice Drying. Accepted for publication in International Food Research Journal, December, 2016.

### Under Revision

M.N. Ibrahim, **M. Ghiasi**, R.K. Basha, R.A. Talib. Air Flow Reversal Drying Performance for Rice with Inclined Bed Dryer. Submitted to Journal of Stored Products Research, October, 2016.

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