UNIVERSITI PUTRA MALAYSIA

FIXED-BED DRYING OF RICE WITH AIRFLOW REVERSAL FOR PRODUCT QUALITY AND DRYING PERFORMANCE

KOBRA TAJADDODI TALAB RASHTI

FIXED-BED DRYING OF RICE WITH AIRFLOW REVERSAL FOR PRODUCT QUALITY AND DRYING PERFORMANCE

By

KOBRA TAJADDODI TALAB RASHTI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the degree of Doctor of Philosophy

February 2012

Dedication

With all my love I dedicate this thesis to my parents

Abstract of thesis presented to Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

FIXED BED DRYING OF RICE WITH AIRFLOW REVERSAL FOR PRODUCT QUALITY AND DRYING PERFORMANCE

By

KOBRA TAJADDODI TALAB RASHTI

February 2012

Chairman: Associate Professor Mohd Nordin Ibrahim, PhD

Faculty: Engineering

In Malaysia, paddy is typically harvested at moisture contents (MC) of around 21% to more than 30% (w.b.) and is dried to 13 – 14 % by using the fixed bed dryer (one direction airflow) at drying air temperature of 42 - 45 °C and grain bed depth of around 100 cm. As drying progresses in this type of dryer, grains near the air inlet are equilibrated with heated air and become over-dried before the grains in top layers reach the target final moisture content (FMC). This leads to non uniformity of grain MC within the entire bed at the end of drying operation.

The main objective of this study is to improve drying process of rough rice using fixed bed drying method by reversing the airflow direction. In order to evaluate the effect of

airflow reversal drying method on rice quality and drying performance, a laboratory experimental dryer was designed and fabricated. The approach was initiated by modifying an existing computer simulation procedure for fixed bed drying to meet the purpose of this study. Matlab software was applied to write the computer simulation program. Graphic User Interface (GUI) was created to show the simulation results graphically and numerically.

The maximum bending strength was close to 35.69 MPa and 33.64 MPa for 55 °C and 60 °C, respectively. The results also revealed that drying air temperature of 40 °C and FMC range of 12 – 13.5% could be appropriate selections to achieve high whole kernel percentage (WKP) for a Malaysian paddy variety (MR219). Glass transition temperature (Tg) for MR219 was observed to be in the range of 9.65 - 61.79 °C, with MC in the range of 26.8 – 7.4% (w.b.). Results fit ability of Zuritz equation showed that it would be suitable to represent equilibrium moisture content (EMC) for computer drying simulation and its parameters were modified based on MR219.

Results of the computer drying simulation that were depicted on glass transition diagram revealed that drying air temperature of 50°C can be recommended as the first temperature to dry paddy with high initial moisture content (above 30%) for 2.20 h in two-stage drying of MR219. Reversing the direction of airflow every 2 or 3 h cannot be recommended especially for high moisture grain due to occurrences of several transitions from rubbery to glassy state and vice versa, as well as several moisture re-

adsorption and re-desorption for grains in the top and bottom layers of the dryer during the entire drying process. The results illustrated that HRY could be improved by changing the airflow direction when MC of grains at bottom layers were above 12%, and at top layers were about 17 – 18% with grain bed depth of 50 cm. In this drying scenario, applying the downward drying air temperature of 36 °C – 36.5 °C may not cause significant HRY reduction after changing the direction of airflow.

Generally, the results showed that drying capacity by airflow reversal drying increased above 20%. Electricity costs decreased 20.44%, 11.99%, 32.33%, 25.17%, and 18.26% for airflow reversal drying with grain depth of 100 cm, 75 cm (G= 59 m^3/min. t), 75 cm (G= 28 m^3/min. t), 50 cm (G= 59 m^3/min. t), 50 cm (G= 35 m^3/min. t), respectively compared to conventional drying.

In order to minimize undesirable effects of high drying rate, recommended superficial velocity and airflow rate ranges could be 0.18 – 0.22 m/s and 43 – 52 m^3/min .t, respectively, for airflow reversal drying with grain bed depth of 50 cm. Although airflow reversal drying with grain depth of 75 cm and airflow rate of 28 m^3/min. t showed more HRY reduction than that of 50 cm drying treatments, but good results of that treatment compared to the other drying treatments (grain bed depth of 75 and 100 cm) indicated HRY could be improved by adjusting the grain bed depth, superficial air velocity (maximum 0.2 m/s) and related airflow rate.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi syarat untuk ijazah Doktor Falsafah

PENGERINGAN 'FIXED-BED' BERAS DENGAN PEMBALIKAN ALIRAN UDARA BAGI KUALITI PRODUK DAN PRESTASI PENGERINGAN

Oleh

KOBRA TAJADDODI TALAB RASHTI

Februari 2012

Pengerusi: Profesor Madya Mohd Nordin Ibrahim, PhD

Fakulti: Kejuruteraan

Di Malaysia, padi lazimnya dituai pada kandungan kelembapan (MC) sekitar 21% sehingga lebih daripada 30% (w.b.) dan dikering kepada 13- 14% dengan menggunakan pengering 'fixed bed' (satu arah aliran udara) pada suhu udara 42-45 °C dan kedalaman lapisan bijirin sekitar 100 cm. Sementara pengeringan berlaku dalam pengering jenis ini, bijirin berhampiran salur masuk udara menjadi sekata dengan udara panas dan menjadi lebih kering sebelum bijirin dalam lapisan teratas mencapai sasaran kandungan lembapan terakhir (FMC). Ini membawa kepada ketidakkeseragaman MC bijirin dalam keseluruhan lapisan pada akhir operasi pengeringan.

Dengan itu, satu kajian dijalankan untuk memperbaiki proses pengeringan padi menggunakan kaedah pengeringan 'fixed bed' dengan menterbalikkan arah aliran udara. Untuk menilai kesan kaedah pembalikan aliran udara keatas kualiti beras dan prestasi pengeringan, suatu pengering makmal uji kaji telah direka dan dibina. Pendekat telah dimulakan dengan mengubah prosedur simulasi komputer yang sedia ada untuk pengeringan 'fixed bed' bagi memenuhi tujuan kajian ini. Perisian Matlab digunakan untuk menulis program simulasi komputer tersebut. Antara Muka Pengguna Grafik (GUI) telah dicipta untuk menunjukkan hasil simulasi secara grafik dan berangka.

Kekuat lenturan maksimum dicapai hampir 35.69 MPA dan 33.64 MPA untuk 55 °C dan 60 °C masing-masing. Keputusan mendedahkan bahawa udara pengeringan bersuhu 40 °C dan FMC berjulat 12- 13.5% boleh menjadi pilihan yang sesuai bagi mencapai peratusan bijian penuh (WKP) yang tinggi untuk varieti padi tempat yang dipilih (MR219). Rajah **'**glass transition' telah dibangunkan untuk MR219, dan digunakan untuk menilai tingkah laku proses pengeringan pada keadaan terpilih. Suhu 'glass transition' (Tg) untuk MR219 berada dalam julat 9.65-61.79 °C, dengan MC dalam julat 26.8-7.4% (w.b). Keputusan keupayaan penyesuaian persamaan Zuritz menunjukkan bahawa ia adalah sesuai untuk mewakili kandungan lembapan seimbangan(EMC) dalam simulasi pengeringan berkomputer dan parameternya telah diubahsuai berdasarkan MR219.

Hasil simulasi pengeringan berkomputer yang telah ditunjukkan pada gambarajah 'glass transition' menunjukkan bahawa suhu udara pengeringan 50 °C boleh disyorkan sebagai suhu yang pertama untuk mengeringkan padi yang mempunyai kandungan lembapan permulaan yang tinggi (di atas 30%) untuk 2.20 jam. Menterbalikkan arah aliran udara setiap 2 atau 3 jam tidak boleh disyorkan terutamanya bagi bijirin berkelembapan tinggi disebabkan oleh kejadian beberapa peralihan dari keadaan bergetah kepada berkaca dan sebaliknya, serta beberapa penjerapan dan nyah jerapan bagi bijiran di lapisan atas dan bawah pengering bagi seluruh proses pengeringan tersebut.

Keputusan yang didapati menunjukkan bahawa HRY boleh diperbaiki dengan mengubah arah aliran udara apabila MC bijirin di lapisan bawah adalah sekitar 12.5% dan pada lapisan atas kira-kira 17-18% dengan kedalaman lapisan bijirin 50 cm. Dalam senario pengeringan ini, menggunakan suhu udara pengeringan menurun sebanyak 36 °C- 36.5 °C (berdasarkan rajah 'glass transition' untuk bijirin dengan kandungan kelembapan 17-18% untuk lapisan atas pengering) tidak boleh menyebabkan pengurangan HRY yang ketara selepas mengubah arah aliran udara.

Secara umumnya, keputusan menunjukkan bahawa kapasiti pengeringan meningkat melebihi 20% hasil daripada pengeringan pembalikan aliran udara. Kos elektrik menurun sebanyak 20.44%, 11.99%, 32.33%, 25.17% dan 18.26% untuk pengeringan pembalikan aliran udara dengan kedalaman bijirin 100 cm, 75 cm

(G = 59 m³ / min. t), 75 cm (G = 28 m³ / min. t), 50 cm (G = 59 m³ / min. t), 50 cm (G = 35 m³ / min. t) masing-masing berbanding dengan pengeringan konvensional.

Dalam usaha untuk mengurangkan kesan-kesan yang tidak diingini dengan kadar pengeringan tinggi, halaju dangkal dan kadar aliran udara disyorkan berada dalam julat 0.18 – 0.22 m/s dan 43 - 52 m³/min. t masing-masing untuk pengeringan pembalikan aliran udara dengan kedalaman bijirin 50 cm. Walaupun pengeringan pembalikan aliran udara dengan kedalaman bijirin 75 cm dan kadar aliran udara 28 m^3/ min. t menunjukkan lebih pengurangan HRY dari rawat pengeringan 50 cm tetapi keputusan rawat tersebut yang baik berbanding dengan rawat pengeringan lain (kedalaman bijirin 75 dan 100 cm) menunjukkan HRY boleh dibaiki dengan menyesuaikan kedalaman bijirin, halaju udara luaran (0.2 m/s) dan yang berkait kadar aliran udara.

ACKNOWLEDGMENTS

My first words of thanks and appreciation are faithfully to Allah who has gifted me the will and patience to complete this academic work. I would like to express my deepest gratitude and respect to my main supervisor, Associate Professor Dr. Mohd Nordin for his professional guidance and supports through the research period. My sincere appreciations are also extended to my supervisory committee members, Associate Professor Dr. Sergey Spotar, Associate Professor Dr. Kharidah Muhammad and Dr. Rosnita A. Talib for their advice to shape my project. My special thanks also go to Dr. Amir Reza Sadrolhosseini for his valuable advice in computer simulation. The facilitating of the technical and lab work of the research has been contributed by a group of people. Among them I would like to thank Mr. Zahir for his valuable help. The finding for this study provided by BERNAS is hereby acknowledged with appreciation.

I certify that a Thesis Examination Committee has met on 23th February 2012 to conduct the final examination of Kobra Tajaddodi Talab Rashti on her thesis entitled "Fixed-Bed Drying of Rice with Airflow Reversal for Product Quality and Drying Performance" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Yus Aniza Yusof, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairperson)

Siti Mazlina Mustapa Kamal 1, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Chin Nyuk Ling 2, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(InternalExaminer)

Shuso Kawamura, PhD
Associate Professor
Graduate School of Agricultural Science
Hokkaido University
Japan
(ExternalExaminer)

_____

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

MOHD NORDIN IBRAHIM, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Sergey Spotar, PhD
Associate Professor
Faculty of Engineering
University of Nottingham, Malaysia Campus
(Member)

Rosnita A. Talib, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sharifah Kharidah, PhD
Associate Professor
Faculty of Food Science and Technology
Universiti Putra Malaysia
(Member)

_____

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations which have been duly acknowledged. I also declare that it has not been previously, and is not currently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

_____

KOBRA TAJADDODI TALAB RASHTI

Date: April 2012

TABLE OF CONTENTS