UNIVERSITI PUTRA MALAYSIA

IMPROVED MATHEMATICAL MODEL OF FIXED-BED INFRARED DRYER PROCESS UNDER DIFFERENT WATER FLUX EXPRESSION

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By

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Thesis Submitted to the School of Graduated Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

December 2013

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DEDICATION

I dedicate my dissertation work to my family. A special feeling of gratitude to my loving parents, R. Al-Musawi and E.Warraq whose words of encouragement and push for tenacity ring in my ears. My brother and sisters have never left my side and are very special.

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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Chair: Siti Anom Binti Ahmad, PhD

Faculty: Engineering

The use of infrared radiation in the drying industry has been increased in recent years due to its advantages over other drying methods. High intensity, precise control and ability to penetrate the product are some of the advantages of infrared radiation. Although infrared radiation has unique advantages over conduction and convection heating methods, the lack of visual feature data related with the radiant process and the complicated mathematics have hampered wide numerical simulation for optimization and process design.

The objectives of this research are to develop a mathematical model of fixed-bed infrared dryer by include suitable form of water mass flux (n_w) for the simulation purpose, modification of the model to be valid and applicable for different kind of materials, numerical solution of the model and finally control the system using PID controller.

New approaches with modifying of the model are presented in three different methods. In method 1 the Equation of water flux is modified and simplified to be substituted in the main model. In method 2, the Equation of the dimensionless water content is added to the main model, as the model becomes a system of 5 partial differential Equations. In the last method, water flux Equation is modified by increases the effect of the emitter temperature on the system performance, as it can be applicable for more variety of food materials.

Nonlinear regression is used to fit the experimental data to the models. Coefficient of determination (R^2) is calculated in order to measure the proportion of variability qualified to the mathematical model, where mean bias error (MBE) and root mean square error (RMSE) were used to evaluate the goodness of fit of each method.

In order to have more efficient and accurate drying performance, all developed models are controlled using PID controller. The moisture content values of three

methods are compared together before and after connecting the models to the controller. Resulting curves show that the first method has the best fitting values with the experimental curves while method 3 reaches the desire moisture content faster than method 1 and 2.All methods show faster drying performance after controlling the process. It may consider as energy and time saving with efficient performance of the system. In this work Method 3 show the best performance for IR dryer that reach desired moisture content of 0.5 (Kg water/Kg dry mater) in 3 hours where it is 3.5 and 5 hours for method 1 and 2 respectively. Developing three methods and designing control strategy are considered as the contributions of this work while the Main contribution is presenting new water flux Equation in method 3.

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

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Oleh
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Penggunaan radiasi infrared di dalam industry pengeringan semakin rancak kebelakanga ini kerana kelebihnannya berbanding kaedah lain. Antara lekebihan radiasi infrared ialah kekuatan yang tinggi, kawalan yang tepat dan kemampuaannya untuk penembusi sesuatu produk. Walaupun kelebihan radiasi infared unik berbanding kaedah pengaliran dan konveksi pemanasan, kekurangan dari segi data visual yang berkaitan dengan proses pemanasan dan matematik yang kompleks telah menghalang simulasi penomboran untuk pengoptimuman dan proses rekabentuk.

Objektif kajian ini adalah untuk membangunkan model sistem pengering infrared dengan kaedah memasukkan 'water mass flux (n_w)' yang sesuai untuk tujuan simulasi, pengubahsuaian model supaya sah dan boleh digunapakai untuk material yang berbeza, penyelesaian penomboran kepada model dan akhir sekali sistem kawalan menggunakan pengawal PID.

Pendekatan baru dengan mengubahsuai model dibentangkan melalui tiga kaedah yang berbeza. Kaedah 1, persamaan fluks air diubahsuai dan dimudahkan untuk digantikan dengan model utama. Kaedah kedua, persamaan tanpa dimensi isi air ditambah kepada model utama. Melalui kaedah kedua, ia menjadikan model sebagai satu sistem dengan 5 bahagian persamaan perbezaan. Kaedah terakhir, persamaan fluks air diubahsuai dengan meningkatkat kesan pemancar suhu kepada prestasi sistem, supaya ia boleh digunapakai kepada lebih banyak jenis makanan.

Regresi tidak linear digunakan untuk menyesuaikan data experiment ke atas model. Penentuan pekali (R^2) dikira untuk menentukan nisbah kepelbagaian yang sesuai/layak kepada model matematik, ralat di mana purata kecenderungan (MBE) dan ralat punca kuasa dua (RMSE) digunakan untuk menilai kesesuaian setiap kaedah.

Untuk mendapatkan prestasi pengeringan yang lebih berkesan dan tepat, kesemua model yang dibangunkan dikawal dengan menggunakan PID. Nilai kelembapan dalam ketiga-tiga kaedah dibandingkan sebelum dan selepas menghubungkan model kepada pengawal. Lengkuk hasil menunjukkan terdapat nilai yang paling padan dengan data experimen dalam kaedah pertama, sementara kaedah ketiga mencapai kelembapan kandungan yang diingini lebih cepat berbanding kaedah 1 dan 2. Seperti

yang dinyatakan sebelum ini, kaedah 2 terdiri daripada 5 bahagian persamaan perbezaan. Berbanding dengan dua kaedah lain, kaedah 2 menunjukkan prestasi yang palig lambat. Selain daripada itu, kesemua tiga kaedah menunjukkan prestasi pengeringan lebih cepat selepas proses dikawal dan mencapai kandungan kelembapan yang diigini dalam masa yang singkat. Maka ia mungkin dipertimbangkan sebagai penjimatan tenaga dan masa dengan prestasi sistem yang berkesan.

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I certify that a Thesis Examination Committee has met on 20 December 2013 to conduct the final examination of Muhmmed Hussain Abdul Sahab on his thesis entitled "Improved Mathematical Model of Fixed-Bed Infrared Dryer Process under Different Water Flux Expression" 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 Master of Science.

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Declaration by graduate student

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